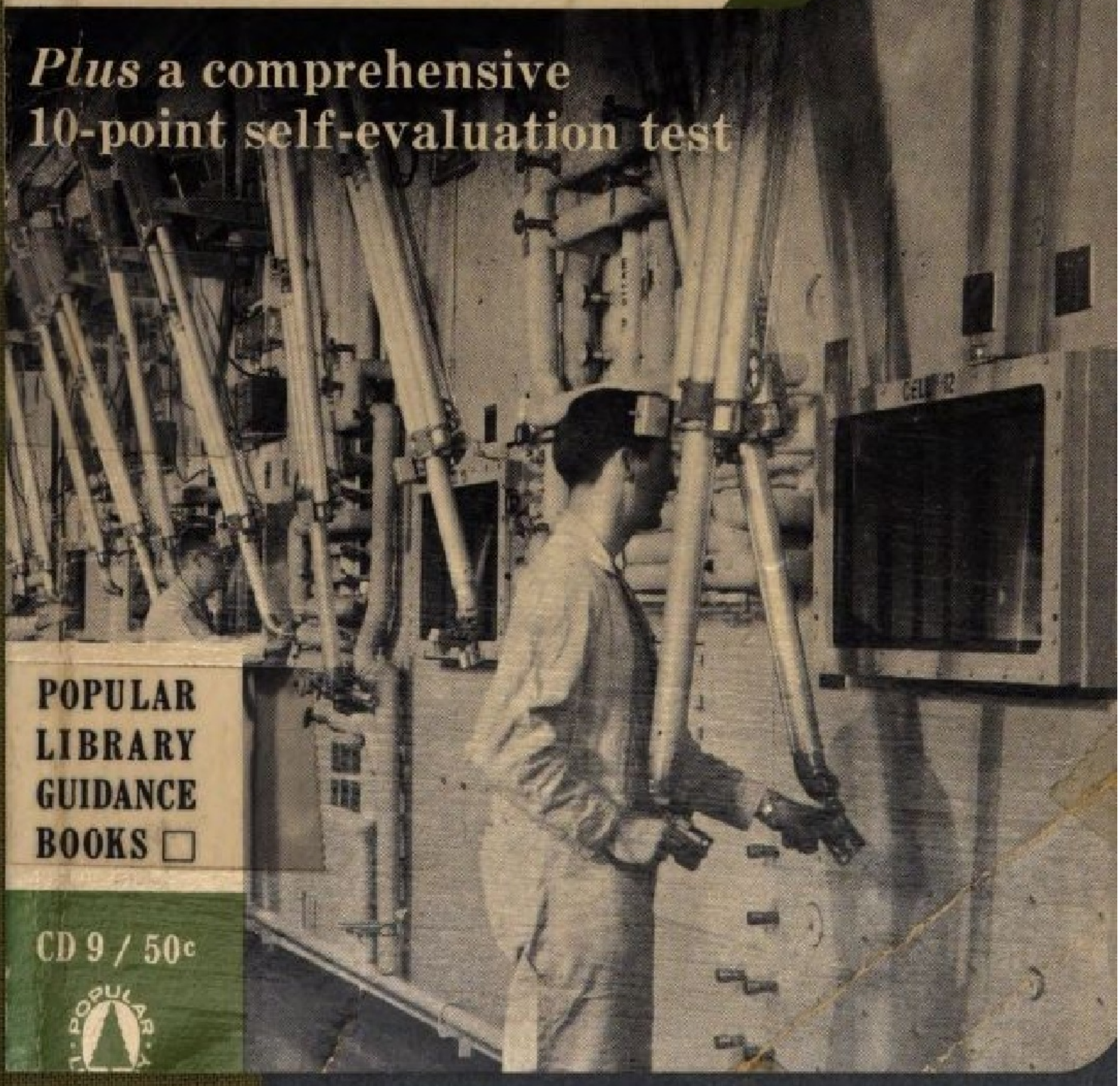
To help you choose the *right* career

Your Future in Nuclear Energy Fields

by William E. Thompson, Jr.
Technical Staff Engineer,
Oak Ridge National Laboratory

Plus a comprehensive
10-point self-evaluation test



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YOUR FUTURE IN NUCLEAR ENERGY FIELDS

is a definitive study of this field that has been made to help you select your life's work. This book will enable you to weigh your own capabilities and ambitions in light of the requirements, the advantages, and the drawbacks of such a career. In the long run, choosing your career early and sensibly will bring you savings in time, effort, and money. Above all, if you make the choice wisely, you will find the satisfaction that only comes with doing the right job well.

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President John F. Kennedy
in his message to Congress
February 20, 1961

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This series of Popular Library Guidance Books is for the student who is looking for the *right* career. All of the books on the list were written by prominent men and women who are successful in their chosen fields.

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Your Future in Nuclear Energy Fields

WILLIAM E. THOMPSON, JR.

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Ninth in a series

in Depth Series .

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About the Author

WILLIAM E. THOMPSON, JR. was engaged in the top-priority job of producing uranium 235 for the first atomic bomb during the Manhattan Project at the "secret city" of Oak Ridge, Tennessee. Concentrating during this period on the electromagnetic separation of uranium isotopes, he returned, after World War II ended, to his chosen field of chemistry in the Oak Ridge Process Development Laboratory, where he served as lab foreman for some time. Finding the nuclear energy field an exciting and challenging one, he decided to stay in it, and became associated with the Oak Ridge National Laboratory (under the direction of the Atomic Energy Commission) as it moved into the new postwar program of radioisotopes production and distribution. Once he had proved himself to be thoroughly familiar with the new technology of processing and handling highly radioactive materials, Mr. Thompson became Technical Staff Engineer for the program as well as the Budget Coördinator for the Finance and Materials Division—both positions that he fills today.

Born in Chapel Hill, North Carolina, in 1923, and a

National Laboratory
ss , and to the general

graduate in chemistry of the University there, Mr. Thompson has done a considerable amount of writing in his field not only for the Oak Ridge National Laboratory but for the AEC as well, and, in addition, for the Institute for Research. Among his many responsibilities is reporting to the AEC, to Congress, and to the general public precisely what has been accomplished thus far in government-supported research and what is contemplated for the future.

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Your Future in Nuclear Energy Fields

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CHAPTER I

Choosing a Career in Nuclear Energy

In the night's blackness before the sun rose on July 16, 1945, a bomb burst over the wastelands of New Mexico. It created brilliant light "many times brighter than the midday sun"; it melted sands of the desert; and it vaporized the steel tower on which it had been mounted. In 1946, a hospital patient drank an "atomic cocktail"; he felt no sensation, but nuclear energy "burned out" cancerous cells in his body. In December, 1952, live steam poured through pipes from a furnace that had no fire; turbine blades turned, and electricity was produced from nuclear energy.

The challenges and opportunities afforded by nuclear energy stir the imaginations of men the world over. What immense possibilities they foresee! Fission of all the uranium in an eight-foot cube releases enough nuclear energy to drive the motors, heat the houses, supply the electricity, run the industrial plants, and meet all other power needs for the entire world for a year. The radiation and radioactivity that men create by nuclear energy methods provide "the most powerful new research tool since the invention of the microscope." Industrial applications for nuclear energy make possible great advances. Doctors find new ways, through nuclear energy, to diag-

nose and treat cases that were hopeless under older methods.

What started out as a top-secret World War II project to develop a devastating new weapon succeeded so well that men said nations would never dare to start another war, lest both sides be completely destroyed. But the end of World War II did not mark the end of work on nuclear energy weapons. Nations were afraid not to have them, and one by one the powerful nations of the world learned how to make "atomic bombs." Still, after World War II ended, much greater effort was devoted to peaceful applications of nuclear energy.

Many nuclear energy opportunities that scientists could foresee at the end of World War II have been developed to a flourishing state. Other newer uses for nuclear energy show such promise that the number of people working in nuclear energy fields increases every year. Moreover, trained personnel for careers in these fields will remain much in demand as the applications of nuclear energy increase. It is about these careers that this book is written, in the hope that knowledge of the challenges of nuclear energy will inspire the coming generation to move forward with even greater strides than their fathers did as pioneers in nuclear energy. For it is true that nuclear energy is so new that students now entering college may very well be sons of the young scientists who in World War II and afterward developed the basic knowledge and applications of nuclear energy.

What Is Nuclear Energy?

Nuclear energy became of tremendous importance to mankind with the invention of the nuclear reactor. This

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is the device that, for the first time, made it possible to tap the almost unlimited power locked in the nuclei of atoms. Ordinarily, nuclear energy is so tightly locked in the nucleus that nothing releases it. This is why the nuclear reactor is the basic tool in nuclear energy fields, for it provides the first practical means of releasing energy from the nuclei of atoms on a large scale.

In a nuclear reactor, uranium atoms provide the nuclear energy. This energy is released by splitting the heavy uranium atom into two smaller atoms. When large numbers of uranium atoms split, tremendous quantities of energy are released. The nuclear reactor is basically a special furnace designed to provide the proper conditions for the splitting (fission) of large quantities of uranium atoms. When uranium "fuel" burns in the nuclear furnace, energy is released by the "burning" (fission). Nuclear energy from splitting uranium atoms is released in the form of invisible radiation. Conditions inside the nuclear reactor are such that everything placed in these becomes radioactive; that is to say, the atoms of which it is composed become radioactive.

The atoms remain radioactive for varying lengths of time after removal from the reactor. The length of time an atom stays radioactive is characteristic of the particular type of atom. When an atom loses its radioactivity, it does so by giving off invisible radiation. Radiation and radioactive atoms are the two basic ingredients of nuclear energy. Radiation is energy. Just as sunlight, another form of radiation, brings energy from the sun, so nuclear radiation brings energy from the nuclei of atoms. This is the only way energy can get out of the nucleus—by radiation. Radioactive atoms are atoms that have too

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The Importance of Nuclear Energy

Why is all of this important to us? Energy is the answer. Radiation cannot be seen, heard, felt, smelled, or tasted, but it can be converted to heat. When an atomic bomb explodes, so much radiation is converted to heat instantly that metals boil away in a blinding flash. But this is uncontrolled nuclear energy; in a controlled nuclear reactor, radiation can be converted to heat to make steam—steady, strong, live steam produced continuously to drive turbines for power.

We have been making steam and all sorts of power for years, so why is nuclear energy important? The importance lies in *how* we make it. In the past, we have burned coal, oil, gas, or wood to produce power. Most people quit using wood long ago because it began getting scarce and it had too many other valuable uses for them just to burn it. Some countries of the world don't have natural resources of coal, gas, or oil. And even in many countries that do have them, suppplies are running short. Coal mines have to be dug deeper to reach new veins, and the coal costs more when you have to dig deeper for it.

Is uranium cheaper or much more plentiful? Not really, if considered on a pound-for-pound basis; uranium costs several dollars a pound, coal several dollars a ton. The United States has large, rich coal fields, but only low-grade uranium ore deposits. Where, then, is there an advantage for nuclear energy? The advantage is in the nu-

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clear energy itself. When coal, gas, oil, or wood burns, the energy released is chemical energy; no nuclear energy is involved. But when uranium atoms split, releasing their nuclear energy, atom-for-atom uranium fission yields about 100 million times as much energy as the burning of coal, gas, or oil.

Now, an advantage of 100 million to one is something to get excited about. Economists who were beginning to worry about the world's dwindling supplies of coal, gas, and oil saw that in uranium we have a new fuel that will be adequate to meet the world's energy needs for hundreds of years. So the situation we are working toward today is similar to the one with wood: We will burn uranium fuel and save coal, gas, and oil for more valuable uses in chemical synthesis or for running automobiles and doing work that uranium fuels are not yet well suited to do.

However, nuclear energy is not just a new fuel for the world's power plants, as important as that is. Nuclear energy radiation is, in many ways, similar to X rays and will do most of the things X rays will do, plus more. For example, it takes a big machine to make X rays; but a small amount of radioactive material, about the size of a pea, will emit much more radiation, and will do it continuously.

Because radiation will pass right through solid materials and because each radioactive atom emits radiation, all sorts of things become possible. While human senses cannot detect radiation, instruments can. By the radiation emitted from radioactive atoms, scientists can follow the course of atoms almost individually as they move through a chemical process or through the human body.

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They can trace the path of radioactive atoms through places that could never be seen before. Radioactive tracers in research and in industry have made possible many important advances.

Agricultural researchers used radioactive fertilizer to study methods of applying fertilizer to crops. The instant the fertilizer was absorbed by growing plants, their radiation-detecting instruments recorded it. They were also able to determine accurately where the fertilizer goes and what it does in the plants to make them grow. Industry uses radioactive tracers to determine when chemicals are completely mixed, for example, or to follow the flow of liquids through pipes. Because radiation will pass through the walls of a pipe, a detector outside the pipe will tell exactly where the radioactive material is.

In applications similar to the uses of X rays, radioactive sources that emit strong radiation have been used to X-ray metals or other solids to find internal flaws. This is done by putting X-ray film on one side of the solid and the source on the other. Radiation passing through the solid makes an image on the film. In one actual case, an entire concrete grain-storage silo was checked in this way. The developed film showed lighter streaks where the steel reinforcing rods were imbedded in the concrete, and proved that the builder had used only half as much reinforcing steel as specified. The structure was dangerously weak, but only the radiation inspection could show this without actually tearing apart some of the concrete. When metals are cast in molds, sometimes air bubbles are trapped in the metal, making a hidden weak spot. Manufacturers who make pipe, valves, and joints for high-

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While radiation passes rather easily through most materials, it often has some effect on the material. For instance, it has been discovered that superior vulcanized rubber can be made by using radiation as the vulcanizing agent. This use of radiation is giving longer-wearing automobile tires. Radiation's effects on human tissues are used to burn out cancerous growth. Medical uses of radiation and radioactive materials have yielded some of the most exciting results.

Uranium fuel for power plants, radiation for industrial applications, new methods for research and medicine, radioactive materials for tracers and for radiation sources —the uses of nuclear energy seem limited only by man's imagination. We couldn't carry enough coal to the moon to run a power plant there, and there's no oxygen to burn it with even if we could. But a nuclear reactor could be carried to the moon to furnish power for a very long time without needing new fuel or oxygen.

Satellites have already been placed in orbit by using radioactive materials to provide their power. A converter that makes electricity directly from the nuclear energy of the radioactive material will provide steady power as long as the material remains radioactive, which may be for many years. Nuclear-powered wrist watches with a small battery about the size of a dime are on the market. Very weak radiation from radioactive material is converted to electricity to run the watch without danger to the person wearing it. The radiation is so weak that it is all absorbed by the case of the watch and so does not even reach the wrist. But it runs the watch.

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Careers in Nuclear Energy Fields

Your future in nuclear energy can go in almost any direction you want, because nuclear energy has such a wide variety of applications. And what is currently unknown about nuclear energy uses will probably far surpass what we now know, because we have really just started.

Any industry, any profession, any trade you can think of probably has nuclear energy opportunities. Doctors use nuclear energy as we have seen; lawyers are on the legal staffs of all companies engaged in nuclear energy work; teachers for nuclear physics and similar nuclear energy courses are very much needed. The most expert welders in the world are employed at nuclear energy research laboratories. Carpenters, draftsmen, physicists, chemists, truck drivers, biologists, engineers of all kinds, metallurgists, nurses, veterinarians, ditch diggers, industrial-relations men, accountants, mathematicians—almost all kinds of workers, from the most skilled to the most unskilled—are involved already in the companies, government laboratories, and universities where nuclear energy work is carried out.

You may be sure that, whatever your special interests are, nuclear energy fields will probably offer challenges and opportunities that will call forth your best efforts. This book gives some basic information to help in deciding whether you would like a nuclear energy career and in choosing the field that interests you most.

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CHAPTER II

Nuclear Energy

Nuclear energy is not something you run into every day—at least, not so you can notice it. People lived on earth for thousands of years without knowing anything about nuclear energy, without using any of it. In fact, it has only been since about 1940 that we have really known anything about nuclear energy, and even in the 1960s we are not using much of it, in comparison to the other kinds of energy we use. Yet, everyone seems to think nuclear energy is very important to us. And it is. This chapter is concerned with understanding what nuclear energy is like, how it can be used, and why it is important.

Radiation from the Atomic Nucleus

Nuclear energy is usually locked up tight in the nucleus of the atom, and it stays there unless something very special releases it. The usual kinds of things that are done to obtain energy do not give us nuclear energy. When we eat food to provide energy for the body's needs, the energy is chemical energy obtained from the oxidation of

starches, sugars, proteins, and the like. When a fire burns, generating energy in the form of heat and light from the chemical reaction of carbon with oxygen to form CO_2, atoms of carbon and oxygen are involved, but not their nuclei. Chemical reactions involve only the electrons, which surround the nucleus in much the same way as our planets surround the sun; and the energy released is chemical energy, not nuclear energy.

When a waterfall is used to turn a wheel that grinds grain or generates electricity, not even atoms as such are involved. This energy is mechanical and depends upon the weight and motion of the water, the wheel, and other parts of the mill or the energy-generating system. There is no nuclear energy in these processes.

We think of the sun as the ultimate source of all our energy. The sun's energy we experience as warm sunlight —nothing nuclear about that! Scientists have discovered that sunlight (indeed, all light) is generated when high temperature or some other source of energy causes the electrons around atoms to jump around in their orbits.

Where, then, do we get nuclear energy? It is not easy to find, and that is why it was unknown until fairly recently.

If we are to be concerned with the fact that nuclear energy comes from the electrons surrounding the nuclei, it will help to understand something about the structure of atoms. The atom is pictured today as a cluster of neutrons and protons closely packed together in a spherical nucleus and surrounded by electrons. The electrons are not attached to the nucleus, but are circling around it in orbits some distance out. The electron orbits follow definite patterns for all kinds of atoms. The orbit closest to

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the nucleus may have one or two electrons in it, but never more. The next orbit may have any number of electrons up to eight, but not more. The third orbit may contain up to eighteen electrons, and the fourth up to thirty-two. No orbit contains more than the latter number of electrons, and each inner orbit is usually full before electrons appear in the next orbit.

Every proton in the nucleus gives it one positive charge; neutrons weigh about the same as protons, but have no charge. The total positive charge of the nucleus is equal to the number of protons it contains. Because the complete atom is electrically neutral, there must be an equal number of negative charges to neutralize the positive charges of the nucleus. Each electron has an electrical charge that is exactly equal to the charge of a proton but opposite in polarity. The proton is positive, the electron negative. To be electrically neutral, the atom must have the same number of electrons in orbits around the nucleus as it has protons in the nucleus. If the atom is missing some of its electrons, it will have a net positive charge and will try to pick up negative charges to balance itself. This is what causes many chemical reactions to take place; that is, atoms lacking some of their electrons, and thus having a positive charge, combine with other atoms having a negative charge to make up a molecule that is electrically neutral even though the atoms making it up are not. Some atoms can become negatively charged by virtue of the fact that when the outermost orbit does not have its normal number of electrons, the atom will pick up additional electrons to fill the orbit, even though these electrons cause the atom to have a net negative charge.

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Naturally Radioactive Elements

The beginning of knowledge about nuclear energy seems to have come about in Germany in 1895, when W. K. Roentgen discovered X rays, or in 1896, when the French scientist, Henri Becquerel, discovered that uranium emitted invisible rays similar to X rays. Soon afterward, the French husband-and-wife team of research chemists, the Curies, found that thorium also emitted invisible rays. Their research on the source of these rays led to the discovery of the new elements polonium and radium. These elements were called "naturally radioactive" because of the radiation they emitted continuously.

Around 1900, the experiments of the Curies and other scientists in Europe showed that the radiation they had observed coming from naturally radioactive elements was not associated with chemical reactions, and that, indeed, it seemed to come from inside the atoms themselves. In 1904, Sir Ernest Rutherford in England discovered alpha rays in the radiation emitted by naturally radioactive elements. Alpha rays, Rutherford learned, behaved like very energetic, invisible charged particles. He found that the normally straight path of alpha particles would curve in a magnetic field. From the direction and the amount of the curvature, it was shown that alpha particles have a positive charge and that they are as large as some atoms. About the same time, other experiments utilizing magnetic fields showed another kind of radiation from naturally radioactive elements. This type, called beta rays or beta radiation, curved in the opposite direction from alpha rays in a magnetic field, indicating a negative charge, and in other ways behaved like a beam of elec-

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Alpha rays curve sharply in one direction as they pass through a magnetic field, while beta rays curve less sharply and in the opposite direction. A third type, called gamma rays, does not curve at all. No experimental evidence could be found to indicate a particle associated with gamma rays. The scientists concluded that gamma rays are just "bundles of energy," which, like rays, contain no particles. Gamma rays are essentially identical with X rays. The experiments they performed about 1905 showed that alpha particles are actually helium atoms with the outer electrons stripped off, leaving just the nucleus. This helium nucleus, missing its usual two negatively charged electrons, has a double positive charge. Being much larger than an electron, it will not penetrate solid material very far even when it has lots of energy. A few sheets of paper will usually stop an alpha particle. The negatively charged electron, the beta ray, is much smaller and can go farther through solid material. But even so, a fairly thin sheet of metal, say one-quarter to one-half an inch thick, will stop most beta rays. But gamma rays, having no electrical charge and no particle, will penetrate comparatively long distances through solid material. Gamma rays, like X rays, will go from several inches to several feet through solids, depending upon the energy of the radiation and the density of the solid.

The newly discovered radiation associated with naturally radioactive elements caused considerable excitement in scientific laboratories. Here was a new phenomenon completely different from anything observed before. It was soon found that this radiation was associated only

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with the few naturally radioactive elements—mainly uranium, thorium, polonium, radium, and a few other heavy elements.

Beta rays, being electrons, could be generated by some force that caused one of the electrons in orbit around the nucleus of the atom to go shooting off, away from its usual orbit. But alpha rays, themselves the nucleus of a helium atom, could come only from the nucleus of the naturally radioactive atoms. After many experiments, it was shown that all three types of radiation—alpha, beta, and gamma—come from the nuclei of naturally radioactive elements. The radioactive nuclei are unstable, and they give up energy plus parts of their unstable nuclei when they emit radiation. And this radiation is truly nuclear energy.

Induced Radioactivity

In 1919, Rutherford observed that when alpha particles were used to bombard the atoms of certain elements, these elements emitted radiation of their own even after the alpha particle bombardment ceased. The radiation they emitted was usually beta or gamma radiation rather than alpha rays similar to those with which they had been bombarded. He found that some elements not naturally radioactive could be made radioactive by bombardment with alpha particles. His method of bombardment was simple. He used naturally radioactive uranium and radium, which continuously emit alpha radiation (alpha particles). The alpha particles go out from a small piece of uranium or radium in all directions, like light from the sun. Thus, to bombard a sample with alpha particles, he simply put a piece of uranium or radium close to it.

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Many scientists eagerly entered into research on the naturally radioactive elements and on induced radioactivity. They began seeking out the secrets of the atomic nucleus and developing theories to explain what they found. A great deal of knowledge about the nature of the atom and about nuclear energy was gained from these experiments in the early 1900s. They learned that the nucleus of the atom has a positive charge and that it is surrounded by a number of negatively charged electrons that are just sufficient to balance the positive charge of the nucleus. They learned that the atomic nucleus is not a single hard core—like a baseball, for example—but rather is made up of small particles grouped closely together, more like a bunch of grapes. As far as they could determine, all the particles making up the nucleus were protons.

From this new knowledge, Niels Bohr, the Danish physicist, conceived a model of the atom that looks much like today's commonly used symbol of the atom, showing a cluster of particles at the center with electron orbits around this nucleus. Bohr's model of the atom was originally developed in 1913.

In 1931, Ernest O. Lawrence, at the University of California, invented the cyclotron to accelerate electrons, protons, or other charged particles. This device uses magnetic and electrical forces to push charged particles at faster and faster speeds and to keep them focused in a thin beam. The particles travel in a flat spiral path between the poles of a strong magnet. Each time they go around the beam of high-speed particles could be used to bombard the nuclei of atoms to produce artificial radioactivity and yield information about the nucleus and its

energy. In 1932, the British scientist, James Chadwick, discovered that atomic nuclei contain particles other than protons—particles about the same size as protons but different in that they have no electrical charge. Because these new particles are electrically neutral, he called them neutrons. It was discovered that, upon being bombarded with a beam of charged particles or with radiation from radioactive elements, certain atoms would eject neutrons from their nuclei. Still further experiments showed that as other materials were bombarded with the neutrons they would become radioactive and emit their own nuclear energy radiation.

Nuclear Fission

Have you noticed how many different countries were involved in the early research on nuclear energy? In Germany, France, England, Denmark, and the United States and in laboratories all over the world, scientists were eagerly experimenting with various aspects of this very exciting new discovery, nuclear energy. In 1934, the Italian physicist, Enrico Fermi, was performing a series of experiments at the University of Rome, bombarding various elements with neutrons to see what would happen. He observed rather strange behavior when the element uranium was bombarded with neutrons. But he was busy with other experiments and did not have time to really look into this strange behavior. In later years, he commented that had he investigated thoroughly, he might himself have discovered uranium fission five years before the discovery was actually made.

As it was, it remained for some German researchers, chemists Hahn and Strassmann with physicists Meitner

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and Frisch, to learn that when uranium atoms are bombarded with neutrons a few of the atoms will split in two parts, releasing tremendous amounts of invisible energy. In other words, they had discovered nuclear fission.

The announcement of the discovery of uranium fission caused great excitement in scientific circles and sent scientists all over the world rushing to their laboratories to see whether they could observe the same phenomenon. They did, and their reports of their experiments make the *Physical Review* for the years 1939 and 1940 interesting reading, even for nonscientists. Before long, it was discovered that when an atom of uranium splits as a result of being struck by a neutron, it emits additional neutrons. Furthermore, these "new" neutrons could cause fission in other uranium atoms.

Hahn and Strassmann identified the phenomenon of nuclear fission of uranium by showing that pure uranium compounds, after being bombarded by neutrons, contained, in addition to uranium, some atoms of lighter elements that were about one-half the weight of uranium and were highly radioactive. These lighter atoms, they concluded, could only have come from uranium atoms splitting in two. They and some physicists showed that almost unbelievable amounts of energy were released from the nuclei as uranium atoms split—about 100 million times as much energy as when the atoms react chemically. They also found that when something is done to reduce the speed at which the neutrons are traveling, more of the neutrons react with uranium atoms to cause fission.

It was not difficult for physicists to calculate that if large numbers of uranium atoms were to split in a short

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period of time, the amount of energy released would be far greater than could be obtained from any other energy source. Also, since additional neutrons are emitted by uranium atoms as they split, they saw a possibility of making large numbers of uranium atoms split in a short time. What they needed was lots of uranium and something to slow down the neutrons to make them work better.

How Energy Is Created by Fission

Back in 1905, Albert Einstein had developed his now-famous equation, $E = mc^2$. This equation, simply stated, means that energy, theoretically, is equal to mass (weight) times the square of the velocity of light, and that it should be possible to convert mass into energy or energy into mass. But nobody knew how to do it; Einstein's equation was believed to be correct but of theoretical interest only. He had developed it from purely theoretical considerations and completely independent of the work that was being done on the radioactive elements at that time. In fact, no one recognized the possible relationship between the equation and nuclear energy until many years later. No one had ever observed such a phenomenon as mass being converted into energy or vice versa, and, in fact, physicists could not imagine a way to observe or test whether the equation were really true.

But when uranium fission was discovered and the tremendous amounts of energy released by fission were observed, scientists wondered where the energy came from. As more experiments were performed and more information was obtained, they made a startling discovery: The total weight of all the pieces of a fissioned

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uranium atom is less than the original weight of the atom before fission. "Where did the lost weight go?" they asked themselves. The combination of an unexplained loss in mass and an unknown source of large amounts of energy suggested that Einstein's equation might be applicable to the fission process. It was. The atomic mass that disappeared was converted into energy in the form of radiation.

Uranium Fission Chain Reaction

By the early part of 1940, scientists all over the world knew there was a definite possibility that, under certain conditions, large numbers of uranium atoms could be made to undergo fission in a short length of time, generating large quantities of heat or possibly an explosion. Fortunately, scientists in the United States were able to gain government support in launching a project directed toward determining whether it would actually be possible, as it appeared theoretically, to create a bomb of unbelievable force that utilized the power created by the fission of uranium atoms. They organized several top-secret groups at universities to perform research on uranium and fission. One was at Columbia University in New York, another at the University of Chicago, and a third at the University of California in Berkeley. As they got their projects underway, they drew the nation's leading scientists into their research groups and also established new groups at other universities.

In 1942, scientists at the University of Chicago succeeded in establishing the proper conditions under which atoms of uranium bombarded by neutrons would split, converting matter into energy in the form of radiation

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and releasing more neutrons, which, in turn, would cause other uranium atoms to split, thereby resulting in a nuclear chain reaction. On December 2, 1942, in an experiment performed in a laboratory under the stands at the football stadium of the University of Chicago, these scientists achieved the first nuclear chain reaction. It was demonstrated that the large amounts of power created by the reaction could be safely controlled. This was the historic moment when the utilization of nuclear energy for the ultimate destruction or benefit of mankind became a real possibility.

Plutonium and Atomic Bombs

Other scientists, meanwhile, had learned that when uranium atoms are bombarded with neutrons, some simply absorb a neutron and do not split. They discovered that this kind of nuclear reaction resulted in the formation of a new element, which they called plutonium. Further work showed that plutonium was fissionable with neutrons and might be even better than uranium for creating tremendous explosions if some method could be devised for making a nuclear fission bomb.

Wartime Manhattan Project

These significant developments led to the establishment of the top-secret wartime Manhattan Project, which was a purely military research-and-development establishment directed toward producing an atomic bomb.

Even before the war, it had been discovered that not all uranium atoms are alike. Some are heavier than others. It was discovered that the lighter atom of uranium, with atomic weight 235, would undergo fission

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when bombarded with neutrons. The heavier atom of uranium, with atomic weight 238, would more often simply absorb a neutron and be transformed into plutonium. Therefore, the Manhattan Project launched two large programs, each directed toward the production of a different kind of atomic bomb material.

First, they built huge plants for separating and purifying the uranium 235 isotope, which they found was present in mined uranium only to the extent of 1 part in 140. One of these plants used a gaseous diffusion process, which had been developed at Columbia University, to separate uranium isotopes; this method was based on the fact that in gaseous form the lighter atoms would diffuse through a membrane faster than heavier atoms. Even though no such plant had ever been built before, the process worked, and the plant is still in operation in Oak Ridge, Tennessee.

Another type of uranium isotope separations plant was built to utilize an electromagnetic process that had been developed at the University of California. In this process, charged uranium atoms are accelerated through a magnetic field, which causes them to follow a curved path. The amount of curvature in the magnetic field is proportional to the weight of the atoms, so the finely focused beam of uranium atoms actually separates into two beams —one of U 235 and one of U 238. It was their hope that sufficiently large quantities of pure uranium 235 could be separated to make atomic bombs. This separation was also successful, and the first atomic bomb exploded was made of U 235.

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trons to produce large quantities of the new element, plutonium. Since it had been demonstrated that a nuclear chain reaction could be established with natural uranium (which is more than 99 per cent uranium 238) and that this chain reaction would produce large amounts of neutrons, it was fairly evident that in the nuclear reactor plutonium would be produced continuously by the reaction between neutrons and U 238. Plutonium could be separated from uranium chemically and then used to make atomic bombs. The project to make atomic bombs from plutonium was also successful, and atomic bombs since then have been made from plutonium as well as from uranium 235.

So secret were these wartime projects that, although they employed thousands of people at each plant, hardly anybody in the country knew the work was going on. Even the workers on the project were not told the full story—only what they needed to know to do their jobs. Consequently, most of the workers, except the scientists, did not really know what they were working on. Many fanciful and often amusing tales were invented to explain what they were doing. One was that they were making a special type of green paint that the Navy was going to use in anti-submarine warfare. This paint—so the story went—would float on top of the water and coat any submarine periscopes. The submarine commander, thinking he was still under water, would continue to move upward until he was high enough to be shot down with anti-aircraft guns.

The plants were located all around the country. Both the gaseous diffusion and electromagnetic plants for separating uranium isotopes were in Oak Ridge, Ten-

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nessee; but they were about ten miles apart, and the workers at one hardly knew of the existence of the other. The plutonium production plant was located at Hanford, Washington, and the atomic bomb research laboratory was at Los Alamos, New Mexico.

Nuclear Energy and Radiation

When uranium or plutonium atoms split, they release energy in the form of neutrons, plus alpha, beta, and gamma radiation and in the recoil motion of the two halves of the atom as they fly apart. As the neutrons, the pieces of the fissioned atoms, and the rays of nuclear radiation collide with other atoms, they give up a part of their energy to the atoms they hit. These energy losses continue until the nuclear particles and rays have no energy left and come to a stop, absorbed by the material they are in. The energy they have given up to other atoms appears as heat. The absorbing material gets hot.

When large numbers of uranium or plutonium atoms split in a short period of time, the material around them gets very hot. In a bomb, the major force of the explosion comes from the almost instantaneous vaporization of metal when fission heat builds up rapidly. In a power reactor, the fission process is controlled so that the release of heat is not so rapid and can be used to make steam to turn electric power generators.

An important point to be recognized is that energy escapes from the nucleus of an atom only in the form of radiation—no radiation, no nuclear energy. Consequently, anyone who is concerned with nuclear energy has to deal with radiation and radioactive materials. Nuclear energy *is* radiation. It can't be seen or felt; it will

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pass right through your body without your knowing it. Even though you are not aware of it, radiation has an effect as it passes through any material. For one thing, radiation can damage human tissues—a fact that is used beneficially in burning out cancerous tissues with controlled exposure to radiation.

Radiation has effects upon any material that it passes through. Sometimes these effects can easily be seen; in other cases they are difficult to detect even with sensitive scientific instruments. But in all cases the effects result from collisions between rays of radiation and atoms and from the energy given to the atom in such collisions. Scientific research on the effects of radiation in all sorts of materials, both living and nonliving, is an important field from which many useful new discoveries and applications of nuclear energy have come.

Radiation and Radioactivity

If you choose a career in some field of nuclear energy work, you will have to be involved in some way with radiation and radioactive materials. This is because, as stated earlier, nuclear energy is radiation, and radiation is released from radioactive nuclei. Because overexposure to radiation may damage living tissues, people working with radioactive materials have to be shielded from exposure to radiation. This involves erecting a thick barrier to absorb the radiation. With this barrier between himself and the radioactive material, the worker does not reach out and touch the material he is working with; he is literally in a different room.

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remote control, through mechanical hands, electronically controlled robots, and other special tools and devices for doing work that cannot be reached by the operator's hands. Even viewing the work is difficult with a radiation shield in the way. Often periscopes, television cameras, or telescopes are used to see around the radiation shield. When you are working with radioactive materials, you cannot avoid using shielding and coping with the problems it creates.

Why Nuclear Energy Is Important

All of the energy used by the entire world up to 1945 was chemical or mechanical energy, not nuclear energy. Burning fires, falling water, blowing wind, and reacting chemicals provided energy in furnaces, wind and water mills, or in electric batteries. But the burning fires were by far the most important of these sources. For thousands of years, wood was so plentiful that no other fuel was needed for fires. But in some countries wood became scarce, and coal, peat, or other fuels were burned. More efficient coal furnaces soon were developed, and coal became the world's major energy source. Then the automobile came along and created demands for gasoline and oil. The development of these as energy sources led us to today's situation where coal, oil, and natural gas are the major energy sources for the world. Other energy sources are still used, but only in very small amounts in comparison to these three.

When men first began to burn coal, there were many places where it could be found almost at the surface of the ground and mined at very low cost. But the coal that

was easiest to get was soon burned, and miners had to dig deeper at greater cost. Oil and natural gas have followed pretty much the same pattern. Costs have risen. Economists who study the world's usage of fuels and the supplies available for future use predict that supplies of the present fuels will ultimately run short. They say that the day is coming when nuclear energy will have to be used extensively to supplement energy from other sources.

Of course, the world will not suddenly run out of coal, gas, and oil. Some countries have never had any of these fuels at all; others have only small resources or deposits that are expensive to mine. In these areas, electric power costs are already high and nuclear power often is cheaper. This is the case in much of Europe and in Japan. Countries with these shortages are now going ahead with the construction of nuclear power plants to provide electricity at lower costs and in greater quantities than they are able to obtain with conventional fuels. This is the trend and it will doubtless continue. As conventional fuels become more expensive, nuclear power plants will be built to produce electricity at lower cost. Fortunately, the known supplies of uranium and thorium, the source materials of nuclear energy, are large enough to meet the world's needs for a very long time.

Nuclear power stations are being built in many parts of the world today. The radioactive materials that are the "ashes" of a nuclear fire must either be put to use or stored where they cause no danger. Much additional research on nuclear energy is needed to help nations and people use it wisely and safely. The career opportunities in nuclear energy fields will be plentiful and challenging.

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CHAPTER III

Radiation

Energy is released from the atomic nucleus only in the form of radiation, which is something unfamiliar to most people. Some basic facts about radiation may help you to understand what kind of work your career in nuclear energy may lead to. First of all, radioactive materials emit radiation continuously at a steady but decreasing rate. Radioactive nuclei are unstable; as noted earlier, they have too much energy. The nuclei emit radiation as a means of getting rid of excess energy so they can relax to a more stable, less highly excited, state.

Nuclei—the Source of Radiation

Once it was thought that the nuclei of atoms were hard cores, like billiard balls. Then it was found that nuclei had positive electrical charges and that the charge was different for each element. The lightest element, hydrogen, had a nuclear charge of 1; the next lightest element, helium, had a charge of 2. Lithium's nuclear charge is 3, beryllium's 4. For each positive charge of the nucleus, there is one negatively charged electron in an orbit

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It was thought for a while that nuclei were made up of clusters of protons, each proton contributing one unit of charge to the nucleus. Then neutrons, which have no electrical charge, were discovered and found to exist in the nuclei of atoms. Indeed, they were found to exist there and nowhere else. If you somehow get a neutron out of the nucleus of an atom, it will soon be absorbed by another atom, or it will decay radioactively and become a proton. Neutrons were found to be about the same size and weight as protons, each of them being nearly 2,000 times as heavy as an electron. In fact, fairly recent scientific experiments show that when a neutron is separated from its nucleus, it becomes unstable and ejects an electron, thereby changing itself into a proton. But inside the nucleus of an atom, for some reason, neutrons appear to be stable, changing into protons only under very special circumstances.

Scientists found that they could explain things very neatly, with both neutrons and protons in the nuclei of atoms, by figuring that the number of protons in the nucleus determines the electrical charge of the nucleus and the number of electrons in orbits around it. This number they called the atomic number. Hydrogen is 1, helium 2, lithium 3, and so on up to element number 92, uranium.

Because neutrons and protons have practically the same weight, which is 2,000 times heavier than the electron's weight, obviously most of the mass of an atom is in its nucleus. If you take a single proton as the nucleus of an atom, the atom has to be hydrogen. If you add a

neutron to this nucleus, it weighs twice as much; but, because it has only one proton, it is still a hydrogen atom —heavy hydrogen or deuterium. Deuterium is an isotope of hydrogen—the same element but different weight. If you add one more neutron to the nucleus, the weight goes up to 3; but the nucleus still has only one proton and is still hydrogen. It is called tritium, another isotope of hydrogen. But tritium really has too many neutrons in its nucleus and is unstable. One of the neutrons emits an electron—beta radiation—and turns into a proton. Now you have two protons and one neutron in the nucleus. It can't be hydrogen with two protons; having an atomic number of 2, it must be helium. But its weight is still three, so it is called helium 3. Add another neutron and you get helium 4.

The number of protons determines the identity of the element; the number of protons plus neutrons determines the weight. Uranium has the atomic number 92, hence it must always have 92 protons in the nucleus. Uranium 235, the stuff bombs are made of, has 143 neutrons in the nucleus. The atomic weight thus is $92 + 143$, or 235. Other uranium isotopes have from 141 to 145 neutrons, giving weights from 233 to 238.

Ordinarily in nature, nuclei with their customary numbers of protons and neutrons are stable. Except for the few naturally radioactive elements, they don't change. When chemical reactions take place, even violent ones like explosions, the nuclei are not affected at all. Only the electrons in orbits around the nuclei are involved. When the stable nuclei are bombarded with neutrons, the bombarding neutrons may cause all sorts of things to happen to the nuclei. A neutron may simply enter the nucleus,

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being absorbed there with little effect except the increase in weight. The energy the neutron brings with it into the nucleus is emitted in the form of gamma radiation. In another nucleus the bombarding neutron may strike a proton, knock it out of the nucleus, and take its place. In this case, the nucleus has the same weight but one less positive charge and consequently is changed to the element of the next lower atomic number. Changes upward in atomic number take place when a neutron is absorbed into a nucleus, which then seems to have too many neutrons. The nucleus corrects this situation by having one neutron emit an electron (beta radiation) and change into a proton, thus increasing the atomic number by 1.

Note that all of these nuclear reactions are accompanied by radiation. The radiation sometimes is emitted immediately, sometimes much later. The emission of radiation is influenced by the stability of the new nucleus. Scientists have found that each radioactive nucleus always follows the same pattern in emitting radiation. The time it remains radioactive—as long as it emits radiation—cannot be measured exactly. Scientists observed that the radiation emitted from radioactive nuclei is always most intense just after neutron bombardment and that it gradually dies out. The rate of decrease in radiation intensity differs widely for various radioactive nuclei. They also found that while they could not measure exactly the time required for the radiation to die out completely, it was comparatively easy to measure the time required for the radiation intensity to decrease by a certain amount. They invented a term called "half-life," which is the length of time required for the radia-

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tion intensity to decrease to half its original intensity. This is the time required for half the radioactive atoms to emit their radiation, to decay to more stable nuclei. It doesn't matter when you start your measurement; after one half-life has elapsed, you will have half as many radioactive atoms as when you started. This is true whether you started with ten radioactive atoms or ten million.

Half-lives for radioactive nuclei vary all the way from millionths of a second to millions of years. Naturally radioactive uranium 235, for example, has a half-life of about 710 million years. Artificially radioactive nuclei formed in a nuclear reactor have been observed with half lives as short as .000001 second. The type and energy of radiation emitted by each radioactive nucleus are characteristic of that nucleus and will always be the same, no matter how the nucleus becomes radioactive. In this connection, it may be noted that other particles than neutrons can be used to bombard nuclei and can enter into or cause nuclear reactions. Among the first nuclear reactions ever observed were those caused by alpha particles. Today, charged-particle accelerators used in research can provide beams of many types, from electrons and protons up to fairly large atoms, to bombard other nuclei and cause nuclear reactions.

Characteristics of Radiation

Understanding a few basic facts about atoms will help you to understand how radiation behaves. First of all, an atom is mostly empty space. The nucleus is pretty solid; but the electrons orbiting around the nucleus are part of the atom, and these comparatively few small

electrons take up a lot of space. If we enlarged the nucleus of an atom to the size of a golf ball, the orbiting electrons would fill the room. Yet, in total size and weight all of the electrons together would be smaller than the head of a pin. So the room with one enlarged atom in it would seem empty except for a golf ball with specks of dust whizzing around it.

If you imagine shooting a shotgun into this room filled by one large atom, some of the pellets might hit the golf-ball-sized nucleus. However, if you fired the shotgun without aiming at the nucleus, probably the pellets would miss it entirely; it would be just chance if the nucleus were hit. If you imagine a very large group of these atoms and if you say that the shotgun pellets must keep going in a straight line until they hit something, then sooner or later all of the pellets will hit a nucleus that stops them.

Radiation passes through solid materials in a somewhat similar manner. The first type of radiation, called alpha radiation, consists of an alpha particle, which is a helium nucleus. The alpha particle, consisting of 2 protons and 2 neutrons, is quite large and has a positive electrical charge of 2. Because of its size and its positive charge, an alpha particle will not penetrate solid matter very far. Usually a few sheets of paper will absorb alpha radiation. But even a sheet of paper is thousands of atoms thick, so the alpha particle passes through many atoms before being absorbed.

Beta radiation consists of electrons, which are very much smaller than alpha particles and which bear a negative charge. Electricity is a flow of electrons; a spark consists of many electrons leaping together across a gap.

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Beta radiation is composed of these same electrons, but not flowing together. Each beta ray is one electron moving at very high velocity. Electrons are small (it takes about 8,000 electrons to be as big as an alpha particle) and are negatively charged. They can penetrate solid materials much farther than can alpha particles. But a sheet of metal one-fourth of an inch thick will absorb most beta radiation. Sometimes, though, high-energy beta rays will penetrate an inch or more of metal.

Gamma radiation is like X rays; it has no particle associated with it but is just a bundle of energy, so to speak. Because of this, gamma radiation will penetrate long distances through solid materials. Concrete is often used as shielding material to absorb gamma rays and protect scientists from radiation while they work with radioactive materials. The thickness of concrete required to absorb the gamma radiation from a nuclear reactor may be seven feet or more. Highly radioactive materials often are placed in lead containers to provide radiation shielding while the radioactive materials are being worked on or moved to another location. Such lead shields may be one foot thick or more. The thickness of shielding required to absorb radiation is governed by the energy of the radiation and the density of the shielding material. A high-energy gamma ray will penetrate any material farther than a low-energy gamma ray. Radiation is more rapidly absorbed in high density (heavy) materials, but it will be absorbed sooner or later even in very low-density materials like air. People twenty miles away from an atomic bomb explosion are not likely to be injured by radiation, for it will have been absorbed by the air before it reaches them.

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Radiation Effects

However freely radiation may penetrate matter, it has its effects upon any material it passes through. In fact, radiation was discovered by a scientist who, noticing the effect it had upon an unexposed photographic film, started looking for the source of this change. In passing through material, radiation may bump into many atoms and bounce off. When this happens, some of the radiation energy is given to the atom. When radiation is absorbed, all of its remaining energy is given to the atom absorbing it.

If the material exposed to radiation has its atoms joined together in molecules, such as a plastic material, for example, the energy imparted to atoms by radiation may break them loose from their molecules. When this happens, the molecules are broken apart. Large amounts of radiation will cause many materials containing complex molecules to decompose. This is especially true of organic materials, which include all living tissues and many other compounds composed mainly of carbon, hydrogen, and oxygen. In crystalline solids—salt, for example—radiation may knock atoms out of their customary positions in the crystal lattice. This does not decompose the crystalline material, but it may significantly change its properties.

In all types of materials, radiation has some effect. Research to determine and measure radiation effects is a major field of nuclear science. In fact, it encompasses several fields. Biological and medical research are very strongly involved in the study of radiation effects on all sorts of living tissues. Solid-state physics is the science most directly concerned with radiation's effects on non-

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living materials. Radiation chemists are extensively involved in the study of radiation's effects on liquids, on chemical reactions, and on chemical compounds.

Not all of the work concerned with radiation effects is pure research by any means. Engineers who design and build nuclear power plants or chemical plants for processing radioactive materials are deeply concerned with the effects of radiation upon the materials they build with. The effects of radiation upon people cause the engineers to be concerned with radiation shielding and with the remote controls necessitated by the presence of a shield between the worker and his work.

Some Applications of Radiation

Radioactive atoms of any element behave chemically just like the ordinary, nonradioactive atoms of the same element. Yet, because of the radiation they emit, radioactive atoms can be followed as they move about. By adding a few radioactive atoms to ordinary atoms, scientists can trace the movements of the ordinary atoms simply by using a radiation-detecting instrument. This technique opened a totally new area of research to scientists in many fields, especially, as mentioned earlier, those concerned with living plants and animals. Previously, materials were located and traced in living tissues by analyzing the tissue. This often required killing the plant or animal or at least cutting off a portion of it to obtain samples for analysis. With radioactive tracers, scientists could follow any substance without even touching the living tissues. By checking the radiation they could tell where the radioactive material was, and by the intensity of the radiation they could tell how much of it

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Tracers can be used in such small quantities that their radiation has no noticeable effect upon living tissues. By using larger quantities of radioactive materials in specific locations, doctors have been able to destroy cancerous tissue; in this process, radiation breaks up complex molecules by knocking atoms out of their normal arrangement. This same effect, when applied to chromosomes of plants or animals, causes genetic changes.

In certain materials, the changes caused by radiation improve the quality of the material. A method of improving automobile tires by exposing the rubber to radiation has been discovered. Some plastics prove to be better for particular uses when they are exposed to radiation. Radiation can make steel stronger under certain conditions. The use of radiation to sterilize foods by killing bacteria after the foods are sealed in containers seems promising. In many cases, the bacteria can be killed by radiation that has no noticeable effect on the food.

Industries have found many uses for radiation. One of the first was to measure the thickness of paper, plastics, or metal produced in long sheets. By the amount of radiation absorbed in the material and the amount passing through, thickness can be determined accurately and continuously while the material is still moving through the manufacturing process. The thickness gauge doesn't even have to touch the material, much less cut out a

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sample to measure. Radioactive tracers are also being used in industry, as noted, before, to follow the flow of materials in pipe lines, to measure the progress of mixing ingredients, and to perform simply a variety of other jobs previously performed not at all or in more difficult ways. Industrial uses of radiation and radioactive materials have already yielded such profitable results that usage is certain to increase, and many new career opportunities will be created.

Radiation Hazards

Radiation can break down the molecules in living tissues; and, if enough of the molecules are broken, the functioning of the tissue may be impaired. Exposure to radiation is thus a potential hazard to those who work with radioactive materials. However, all people everywhere in the world are exposed to some radiation from which they suffer no ill effects. X rays represent the strongest radiation to which most people are exposed, but these ordinarily cause no trouble. Cosmic rays bombard all parts of the earth continuously, and people everywhere are exposed to small quantities of cosmic radiation.

Intense radiation for a very short period of time or mild radiation continuously apparently cause no ill effects for most people. The hazard is from exposure to too much radiation. Because radiation cannot be detected by human senses, the worker must rely upon his understanding and training to remind him of the necessity for protection from radiation. He must use instruments to detect and measure radiation that he might not otherwise suspect is present.

Another potential hazard is from radioactive materials themselves. Because any container in which radioactive material is placed will provide some shielding, radioactive materials that are spilled or that leak out of their containers are especially hazardous. The greatest danger is that the radioactive materials will be breathed, eaten, or absorbed into the body. When radioactive materials are inside the body, there is no shielding at all; and every bit of radiation they emit goes directly into tissues of the body. Consequently, nuclear energy workers must be continually alert to avoid spillage, leakage, or other accidents that allow radioactive materials to escape from their containers. The search for radioactive materials that have become deposited in places they are not supposed to be is continuous and is an essential part of the radiation protection work that must accompany all nuclear energy activities. If radioactive material is found where it is not supposed to be, workers face the job of cleaning it up or somehow getting rid of it.

Nuclear energy installations have very strict rules about radioactive contamination. They check for contamination of the air and the water in the drains as well as contamination of the equipment, the floor, the laboratory benches, and other areas where radioactive materials might unsuspectedly have spread. When radioactive materials are found in these places, nuclear energy workers must decontaminate all solid surfaces and must collect and dispose of all liquids or other materials that have become contaminated. Control of radioactive materials and decontamination are important aspects of radiation protection, and all nuclear energy workers must master them. Therefore, anyone who chooses a career

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CHAPTER IV

Industrial Careers

In the United States, nuclear energy development and exploitation were originated by the federal government during World War II for the purpose of providing a new weapon. During the course of the wartime program, it became clear that nuclear energy had many more applications than just destruction. Nevertheless, until the end of the war, weapons remained the only important goal. Throughout this period, all of the work was performed directly by or for the federal government. After World War II, the government relinquished its tight controls over nuclear energy activities and reorganized the nuclear energy program to encourage participation by private industry. The opportunities for industrial applications attracted growing numbers of companies, soon after the war, to enter nuclear energy work—usually, some aspect of producing electric power from nuclear energy. Since that time, both the number of companies involved and the kinds of business activities have been increasing rapidly, and have created many new career opportunities.

The nuclear power industry utilizes uranium and thorium as its major raw materials, and these must be

mined as ores, purified, and converted into the proper form for use as nuclear reactor fuel. Many nuclear reactors use fuel consisting of uranium, in which the isotope uranium 235 has been increased in concentration. Therefore, we can expect that production plants for the separation of uranium isotopes will continue to be an integral part of the nuclear power industry. Another vital area is the preparation of nuclear reactor fuel. Next are the activities associated with the operation of nuclear reactors to produce electric power. Spent fuel from the nuclear reactors must be processed chemically to remove the fission products and other contaminants, making the unconsumed uranium available for re-use. Finally, the fission products and other radioactive materials, which are the by-products of nuclear power-plant operation, must be prepared for some special use or stored as unusable wastes. Both the utilization of radioactive materials and the disposal of radioactive wastes are important and growing industrial activities.

Raw Materials

In the field of raw materials, careers will be available to geologists who find the ore deposits, to mining engineers who extract them from the ground, and to chemical engineers and metallurgists who recover uranium and thorium from the ores and convert them into the required forms.

While there may always be a place for the prospector looking for uranium ore outcroppings with his Geiger counter, industrial careers are more likely for trained geologists who use scientific methods of searching for

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new ore deposits. Modern techniques include prospecting from a low-flying airplane, using a very sensitive radiation detector to indicate areas where higher than normal radiation levels suggest that radioactive ores may be present. Promising areas can be intensively explored by using the modern core-drilling machine, which provides samples of rock from deep beneath the surface. While the geologist may spend much of his time outdoors in active searches for new ore deposits, he will be aided by many other laboratory and office workers. For example, ore samples will be analyzed by chemists in the laboratories. Chemists who start their careers in the ore analysis laboratories may later move out into the chemical-processing plants where uranium is extracted from the ores and purified.

The actual mining operations are carried out under the direction of mining engineers who are specially trained in methods of getting ore out of the ground and in separating the ore from the rock in which it is found. Careers in this field should appeal to those who like to work with machinery and to work with men in the open areas of the mines and mills.

After the mined ore is crushed and separated from rock in the mill, the work of the chemists and chemical engineers begins. Theirs is the job of running the chemical plant where uranium is extracted from the ore and purified. Usually, these chemical plants are located relatively close to the mines, which, in the United States, means that most of them are in the West, principally in Colorado. Other major mining and raw-materials centers are found in Canada and in the Belgian Congo. Uranium

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exploration is now world-wide, and it can be expected that careers in foreign countries will be open to those who are interested.

Isotope Separation

The separation of uranium isotopes requires such a large and complex plant that in this activity there will be careers for many kinds of people. Perhaps the principal needs are for chemical and mechanical engineers, but chemists, physicists, metallurgists, electrical engineers, and other specialists are also required. The gaseous diffusion process that is used for separation of uranium isotopes is fundamentally a physical process, but it requires many types of specialists to keep the plant running. The purified uranium oxide from the ore processing plant must be converted to uranium hexafluoride, which is the feed material for the gaseous diffusion plants. This chemical conversion requires additional chemical plant facilities in which chemists and chemical engineers perform large-scale chemical operations that are essentially no different from those of industrial chemical plants all over the country. This type of chemical processing is required only for uranium that is to be put through the gaseous diffusion plant for separating and concentrating (or enriching) the fissionable isotope, uranium 235. Many nuclear reactors do not require enriched U 235 for their fuel, and, therefore, the uranium they use does not have to go through the gaseous diffusion plants.

Reactor Fuel Preparation

The preparation of reactor fuel is principally a job for metallurgists, but here again it is such a complex

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activity that several other types of specialists also will be needed. The major skills involved are making uranium metal alloys, casting or working these alloys into the desired shapes, giving them an outer coating of some protective metal, and machining, assembling, and welding to make a finished fuel element.

As more and more nuclear reactors are constructed, the fabrication of fuel elements for these reactors will provide increasing numbers of careers for metallurgists, in particular, for mechanical engineers who will supervise the fabrication of finished fuel elements to meet rigid specifications, and probably for chemists and chemical engineers who will be concerned with the recovery of uranium from the scrap of metallurgical and fabrication operations.

In all of the work described, the principal material involved, uranium, is naturally radioactive, but its radiation is so weak as to offer very little hazard. Problems arising from radiation hazards are primarily concerned with inhaling uranium dust or vapors or with ingesting uranium into the body through the mouth or through skin abrasions. In the work described hereafter, highly radioactive materials will be involved, and problems arising from radiation will be much more complex.

Reactor Operation

The operation of nuclear power plants will be the responsibility of engineers, and probably the type of engineers sought after for careers in this field will be the new graduates of reactor engineering schools. But, again, chemical engineers, electrical and electronic engineers, and other specialists will also be required to perform

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It is interesting to note that the nuclear reactors associated with electric power plants will probably operate so smoothly and steadily that the work of the operating crew will be quite routine. At least that has been the experience over the past several years in the operation of research and production reactors at the AEC's various installations. Probably only the supervisors of the nuclear power plants will be graduate engineers. The operators will very likely be technicians who are high-school graduates.

In normal operation of the nuclear reactor, the major activities that involve handling highly radioactive materials will be associated with removing spent fuel from the reactor. If it becomes necessary to make repairs on the reactor or any of its components, radiation exposures will again be minimized by the use of special remote-control tools. Even today, there are such remote-control tools as automatic welders, which can do a job while the operator stays a considerable distance away. Thus, careers in the field of nuclear power plant operation will be similar to those in the operation of conventional power plants, but will be somewhat more complex.

Fuel Reprocessing—Fission Product Utilization

The reprocessing of spent reactor fuel is the concern of chemical engineers, but it also will require the services of analytical chemists, chemists, and other specialists.

In the operation of most reactors, the fuel must be processed after about 20 per cent of the fissionable material has been consumed. This is required because fission

products accumulate to a point where they interfere with the operation of the reactor. Chemical processing removes the fission products so that the fuel may be re-used. Chemical processing of highly radioactive reactor fuel must also be performed with equipment that is enclosed by thick concrete shielding and operated by remote control. Although the chemical processes may be quite similar to those used in other chemical industries, remote-control operation introduces many important differences. For example, it is not possible to look and see whether a particular tank is full or empty. The tank will be completely hidden by the shielding around it, so a liquid-level gauge must be used to tell how full the tank is. One cannot pour or pump chemicals in the usual manner for two reasons—the shielding that protects personnel from radiation prevents any sort of manual operations; and, also, spills or leaks that let radioactive materials escape are dangerous..

Industrial careers in the chemical processing plants will not be limited to chemists and chemical engineers. Electronic engineers will provide many of the remote-control devices and will keep them operating. Mechanical engineers will assist in remote-control operations by devising apparatus to meet special needs and solving the day-to-day problems of handling highly radioactive materials.

Other activities required to separate and purify radioactive fission products that have been removed from the fuel will be associated with the chemical processing of reactor fuel. The fission products can be sold to industries or other organizations for use as radiation sources or as special materials for research or production applications.

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The fission products may require special treatment to obtain the form desired by the buyer, and this suggests that careers will be available in the highly specialized field of performing chemical, metallurgical, and mechanical operations on very small quantities of highly radioactive fission products. Sales engineers and salesmen will be required to promote the utilization of these potentially profitable by-products of reactor fuel processing.

Waste Disposal

The preparation of fission products into useful forms and the disposal of radioactive wastes are activities of major concern to chemical engineers and of equal concern to health physicists, who will measure and evaluate job hazards from radioactivity and who will assist in protecting personnel from these hazards.

The radioactive by-products of reactor fuel processing that cannot be sold or effectively utilized must be classed as wastes. Radioactive wastes, which may be gases, liquids, or solids, must be stored in shielded, leak-proof containers in a place where they will not create a hazard. Because this type of storage is expensive, there will always be great interest in minimizing the quantity of material to be stored and in developing economical methods of storage. If uses can be found for most of the radioactive materials, they will not have to be stored. Those wastes that are stored will have to be checked periodically to assure safe storage.

Health Physics

A completely new type of career in nuclear science and technology is in the field of health physics. In this oc-

cupation, the protection of personnel, plant, and animal life from radiation hazards is the primary concern. The health physicist must be able to utilize various types of instruments to detect potentially hazardous radiation, to determine its source, and to recommend protective action. He must be able to detect radioactive materials that have leaked out of their containers or been spilled. He will determine the extent of the contamination by radioactive materials, recommend corrective and protective measures, and exercise complete authority over work activities that may involve exposure to radiation or radioactive materials. In addition to measuring the intensity of radiation, the health physicist will be responsible for sampling water from streams near the plant, chemical wastes from the processes, and other materials to determine whether they have become contaminated with radioactive materials. His job is to detect and control hazards from radiation and radioactive materials, no matter where or how these hazards occur.

Electronics

Since all fields of nuclear science and technology are concerned with radiation and radioactive materials, there is a particular need for electronic engineers to develop and construct electronic instruments to detect and measure the invisible radiation. The controls for nuclear reactors are based on electronic devices, as are many of the tools of research and development. Remote-control operations introduce special requirements for electronic instruments and equipment that will make these operations possible. Remote-control panel boards for process

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Special electronic devices such as computers—the electronic brain—aid in solving the complex problems of nuclear science and technology. For example, special computers, called "reactor simulators," are built to imitate the performance of a particular nuclear reactor under all sorts of operating conditions. These simulators can be made to operate standard reactor control instruments so that one can figuratively operate the reactor and observe its behavior under all conditions before the reactor is constructed.

The contributions of electronics to nuclear science and technology are immeasurable, and the need for electronic engineers will grow as nuclear energy activities expand.

Advancement in Industrial Careers

In most companies, professional personnel working in the fields described are given job titles that are descriptive of their principal field of work. For example, after receiving a B.S. degree in chemical engineering, a young man may be hired for the position of junior engineer or perhaps in some companies he may have the title of junior chemical engineer, junior development engineer, junior design engineer, or junior process engineer, according to the practices of the company and the type of work he pursues. He can expect that in the normal course of advancement he will become an assistant engineer, or perhaps he will be called assistant chemical engineer and then associate engineer. The next step is to become a full-fledged engineer or chemical engineer, and then a senior engineer. After this, he may become chief engineer.

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It should be noted that advancement through this series of positions is for those who continue to follow their professional careers. In almost any company, it is possible at various stages of professional development to switch from purely professional activities to management or administrative work, where the job title will be more descriptive of the business functions performed rather than the professional activity. For example, a chemical engineer may become head of the pilot plant and have the title of pilot-plant department superintendent, pilot-plant division director, or possibly pilot-plant group leader, depending upon how the organization is set up and what practice the company follows.

In the normal course of events, a junior engineer can expect to advance to assistant engineer after he has gained one or two years' experience and then to qualify as associate engineer in another year or two, and finally to reach the status of full-fledged engineer after he has had about five or six years' experience. After seven to ten years, he may become a senior engineer, and then, as his responsibilities and experience increase, he may attain the position of chief engineer after something like fifteen years. It should be noted that the job titles and rates of advancement differ quite widely with various companies and various individuals in the companies. However, the examples given represent reasonably typical cases. In most companies, it is the practice to use corresponding sequences of job titles for advancement in all technical fields. Thus, a physicist would go through the steps of junior physicist, assistant physicist, associate physicist, physicist, senior physicist, and chief physicist.

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influenced by the shortage of scientific and technical personnel and by general business conditions. Currently, recent college graduates are being started at salaries that are generally higher than the salaries in other fields, especially in cases where the person is particularly well qualified. It is difficult to establish even a typical top salary for the professional man because so much depends upon the company for which he works and the type of responsibilities. However, it is not uncommon for professional personnel, working on purely scientific or technical matters, to achieve salaries approximating those paid to individuals in top management, such as a plant manager or a director of research.

Power Industry's Supporting Services

Like the automobile industry, the nuclear power industry will require the services of many outside companies to provide services, materials, or equipment of a specialized nature. There are many companies in the nuclear energy business today, and while their services, at present, are utilized mainly by government nuclear energy installations and by universities or private research organizations, it can be expected that the development of a nuclear power industry will mean a tremendous increase in business for those companies already established and will also result in the establishment of new companies.

Reactor Designers and Builders

Already some companies have established nuclear power divisions or formed new subsidiaries to engage in

their nuclear power activities. There are several large organizations now engaged in the business of designing and constructing reactors for research or for power production. Inasmuch as the design and construction of reactors is a highly specialized technical field, companies of this sort will undoubtedly continue to provide the basic designs and to carry out the actual construction of reactors and power plants needed by the electric power industry. It is doubtful that many electric power companies will attempt to design and build their own nuclear power plants.

Component Manufacturers

In addition to the companies that design and build reactors, there are others that manufacture the special types of equipment and materials needed in the fields of nuclear science and technology. Most of these have entered the business by simply expanding the lines of products they previously manufactured to include items specially designed to meet the particular needs of nuclear power plants or other nuclear energy activities. The business of providing components for nuclear energy operations and of designing and building reactors will provide career opportunities on an increasing scale for many years to come because the long-term growth of the nuclear power industry seems assured. Careers with companies engaged in manufacturing materials or components for reactors will differ very little from the usual industrial careers in the companies, although specialized knowledge of nuclear science and technology will be required.

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By-product Utilization

Those who utilize the radioactive materials that are by-products of reactor operation require supporting services from a broad segment of industry. They need radiation detection and measuring instruments and special industrial apparatus like thickness gauges. They need such things as hospital teletherapy units, which utilize the radiation from radioisotopes as a substitute for the X rays of a conventional X-ray machine. Many need remote-control devices such as mechanical hands, or manipulators.

Many companies are also engaged in the business of processing particular radioisotopes into unusual forms to meet a particular customer need. An example of this type of activity is the pharmaceutical manufacturer who prepares drugs labeled with radioactive atoms for doctors and other research scientists to use in tracer studies. Special services that may be provided include the analysis of radioactive materials; the decontamination of equipment, clothing, or other items on which radioactive materials have been spilled; and perhaps the disposal of radioactive wastes.

Although the companies providing these supporting services are just beginning to get established, it appears that they will continue to grow in number and business volume. Many opportunities for careers in nuclear science and technology will be offered by these organizations.

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CHAPTER V

Applied Research and Development

The goals of fundamental research in all fields are knowledge and understanding. In basic research, the scientist is concerned with knowledge and understanding for their own value; theoretically at least, he does not care what the answers turn out to be as long as he knows them and understands them. When research is performed for the purpose of obtaining a particular result—when the scientist cares what his answers are and tries to find the conditions, materials, or methods that will give the best answers to solve a particular problem—this is applied research. To put it another way, a scientist performing basic research may measure the strengths of many metals. He may seek to determine how and why alloying metals with each other influences the strength. In applied research, the work might be very similar, with the difference that the scientist would perhaps be seeking the strongest metal and then trying to develop alloys that would make it stronger. Basic and applied research may often be very similar, but applied research places emphasis on finding ways of obtaining the desired results.

Engineering

Nuclear energy fields rely heavily upon engineering. Much engineering research is needed because the nuclear reactors, the remote-control apparatus in shielded cells, and even the equipment for performing basic research are so different from the usual products of industry. Often more time and money go into learning how to make something than will go into actually making it.

Nuclear engineering is a new field that has developed in the past ten years or so in response to the need for technical personnel trained in the special problems of radiation, radioactivity, and nuclear reactions. Nuclear engineering is the field of specialization for people who develop, design, and build nuclear reactors, plants for processing radioactive materials, and other facilities needed for research or production activities in this field. There are many types of engineers in nuclear energy work, just as in other industries. Chemical engineers, mechanical engineers, electrical engineers, and civil engineers all apply the broad knowledge of their fields to specialized problems in nuclear energy. Even more specialized work is chosen by engineers who follow careers in design work, in development, in operation of plants and facilities, or in maintenance.

In applied research, engineers are mainly concerned with development and design, with building and testing pilot-plant models, and sometimes with small-scale production operations using pilot plants. Their work is concerned with learning how to do something or build something and then with finding ways to make improvements. Nothing is ever completely finished to an engineer;

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Nuclear Reactors

So new and different from anything we have known previously are nuclear reactors that a tremendous amount of engineering and scientific development has gone into learning how to build them. New materials are required; new kinds of equipment, new design concepts (to include radiation shielding, for example), and much development and testing are needed to provide the complex parts that will work as they should under the severe conditions created by nuclear fission in a power reactor. Today, nearly twenty years after building the first nuclear reactors, nuclear scientists and engineers are working on a larger scale than ever to develop more advanced types of power reactors.

Accelerators

Charged-particle accelerators, the "atom smashers," are major tools for nuclear physics research. The high-energy accelerators, those providing particles with energies in the billions of electron volts, are tremendous and complicated machines. In response to needs for developing, designing, constructing, and operating such large research devices, a new field called engineering physics is coming into being. In this area, physicists are given specialized additional engineering training to provide the background needed for work that is somewhat different from that usually pursued by physicists.

The large accelerators use as much electricity as a small town; they have the most powerful magnets in the

world; the path of the accelerated particles often is a circle several hundred feet in diameter; the particles must be kept in focus by strong magnetic fields as they travel at nearly the speed of light through a tunnel. The engineering feats involved in building a successful accelerator require applied research and development based on the most advanced technology.

Fusion Devices

After the end of World War II, nuclear energy research led to the development of the "H Bomb"; in this device, the awful power of nuclear fission bombs was increased by additional energy obtained from nuclear fusion. For many years it had been known that at the temperatures reached in the sun (millions of degrees), atoms of the light elements like hydrogen and helium fused together to make a single larger atom and that when this happened, tremendous energy was released. This nuclear process, in fact, is the source of the sun's energy. Scientists found ways to use the high temperatures in a nuclear explosion to cause such fusion reactions to occur on earth. Because of the high temperature at which these nuclear reactions take place, the name applied to them is thermonuclear fusion.

Having achieved thermonuclear fusion explosions, the scientists set out to develop methods of releasing this energy under controlled conditions. Because hydrogen, a common and cheap element (water is two parts hydrogen, one part oxygen), can be made to liberate nuclear energy through the fusion process, a controlled thermonuclear reaction would produce tremendous amounts of energy at very low fuel cost. In addition, the supply of

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The conditions required to achieve controlled thermonuclear fusion reactions are so complex that scientists have not yet been successful. However, it is clear there are several basic requirements that must be met. The fusion reactions must take place in a nearly perfect vacuum. The nuclei must somehow be heated to a temperature above a million degrees. Because the temperature of millions of degrees would melt the walls of any known material, the fusing nuclei must be confined and kept away from the walls by magnetic force.

The difficulties of achieving controlled thermonuclear reactions are extreme, but the benefits are so promising that work in this field of applied research and development will offer many career opportunities. These careers will be available mainly to physicists and engineers but also to chemists, electronics experts, and other specialists in the physical sciences.

Chemical Processes

The raw materials, products, and by-products of nuclear energy are substances about which very little was known prior to 1940. Since that time, applied research and development on the technology of processing radioactive nuclear energy materials have been of major importance in the United States nuclear energy program.

Chemical processing of nuclear energy materials differs from similar operations in most other industries in two principal ways: The radioactivity of the materials being processed often requires the equipment to be shielded and the operations to be remotely controlled;

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and the purity of the products must be unusually high because even small quantities of radioactive impurities can emit comparatively large amounts of radiation. The combination of these requirements has necessitated the development of a new technology for chemical processing of nuclear energy materials. The need for applied research and development in this field will continue as cheaper and better processes are sought.

Weapons and Explosives

A major part of the United States nuclear energy program has been the development of nuclear energy weapons. Applied research for the development of new weapons is centered in government laboratories under the Atomic Energy Commission. Because of military security, most of this work is still in the secret category.

An interesting new field is the utilization of nuclear energy in explosives for civilian applications. This work, also under the Atomic Energy Commission, is directed toward using nuclear explosives for large earth-moving jobs where the cost of conventional explosives, labor, and machinery would be prohibitive. The development of new types of nuclear explosives for this application is a field of applied research that may grow rapidly when successful tests have been conducted.

Space Vehicle Applications

Because nuclear fuel releases so much more energy per pound than other fuels, it is a logical possibility for use in space vehicles, where weight is important. Both the space-vehicle research and the nuclear energy applications are so new that much research and develop-

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Similarly, in our rapidly advancing scientific age, it is probable that other new uses for nuclear energy will grow out of present or future research and will create needs for new undertakings in applied research and development.

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CHAPTER VI

Nuclear Energy Research

Nuclear energy reached the stage of large-scale application about 1944, during World War II. By that time, some of the fundamental discoveries of nuclear physics had been made, but still so little scientific knowledge was available that a tremendous research program had to be undertaken by the government to develop and produce nuclear weapons. Government research laboratories established during the war have continued to grow. Even after nearly twenty years, the government still pays for practically all nuclear energy research, both in government laboratories and in universities and colleges. However, private industries are now undertaking nuclear energy research on a growing scale, as the possibilities of industrial use are becoming more widely understood.

What Is Nuclear Energy Research Like?

One principal characteristic of nuclear energy research in all fields is that radiation is involved—that is, there is an invisible force. Thus, researchers have to rely on electronic instruments for practically all information. Since you cannot *see* what is happening, you need a

special ability to visualize nuclear phenomena on the basis of data from scientific instruments. Virtually all the information about nuclei and nuclear energy is, in a sense, secondhand information. You can't weigh a nucleus; it is too small. You can't see a nuclear reaction for the same reason. So scientists must compute the weight of a nucleus from some other property they can measure; they must visualize nuclear reactions from the information their instruments give them.

For about fifty years, scientists have been trying to visualize what a nucleus looks like. They have been trying to imagine a much enlarged model of the atom to help them understand and explain the phenomena of nuclear science. They have not yet reached complete agreement. Several times they thought they had a good model of the atom only to find some new data that showed their model was not quite right.

Physics

It is the main job of the nuclear physicists to obtain, understand, and explain information about the nucleus and nuclear reactions. Since nuclear data can be obtained only indirectly by measurements on something other than the nucleus itself, they must devise experiments in which they can make a measurement that will enable them to calculate, visualize, or better understand some quality or quantity associated with the nucleus. Most frequently, this is done by bombarding nuclei with some type of nuclear particle and seeking to determine what happens by measuring the radiation given off, the changes in the nuclei being bombarded, and the changes in the bombarding particles. Many experiments are performed

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in a nuclear reactor with neutrons as the bombarding particles. For other types of bombardments, particle accelerators are used—linear accelerators, cyclotrons, synchrotrons. These accelerators provide many different kinds of charged particles—electrons, protons, alpha particles, even the nuclei of larger atoms—to use in bombarding nuclei and cause nuclear reactions.

Nuclear physicists, then, are concerned with performing experiments in which they seek to measure quantities from which, by using physical laws, they can compute or deduce characteristics of the nucleus or its radiation. The experiments may be concerned with the type and energy of radiation emitted from the nucleus, with shielding for radiation, with the forces that hold a nucleus together, or with nuclear fission reactions. The physicists may seek to devise an experiment to test the validity of a new theory or to obtain data needed in developing a theory. Their work covers all aspects of radioactivity, radiation, and nuclear reactions. They work on nuclear power reactions, giant atom smashers, atomic bombs, nuclear power plants for space travel, and nuclear fusion.

Chemistry

Since chemistry is entirely governed by the electrons outside the nucleus, one might wonder at first what chemists have to do with nuclear energy at all. But since the very earliest days of nuclear energy, they have played a vital role—indeed, the Curies, who discovered radioactivity, were chemists, as were Hahn and Strassmann, the discoverers of uranium fission.

The work of chemists falls mainly into two fields—the fundamental chemistry of radiation effects on chemi-

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cal compounds and chemical reactions, and the chemistry of nuclear energy materials, such as uranium, plutonium, radioisotopes, and other substances that must be chemically processed. Most nuclear energy chemical research is in the fields of inorganic and physical chemistry because of the nature of the substances involved and the information being sought.

Chemical reactions always involve energy. Some reactions free energy, usually in the form of heat; others require energy (heat) to be added before they will take place. This suggests that nuclear energy, in the form of radiation, might have some effect on the chemical reactions, and indeed it does. Many chemists are engaged in research to determine what effects radiation has and how it causes these effects. Most often, the chemists work with small amounts of radioactivity, which require little shielding and thus can be used in relatively standard chemical laboratories. However, some types of chemical research require large amounts of radioactivity; and this research must be carried on with the usual remote-control methods and shielding.

Chemical research on nuclear energy materials covers a broad field. It includes research on methods of separating and purifying uranium and thorium from their ores. It covers the development of chemical methods to convert uranium and other nuclear energy materials into the many chemical forms in which they are needed. When fuel is "burned" in a nuclear reactor, much of the uranium is left in the "ashes" removed from the reactor; but it is then mixed with about 35 other highly radioactive elements formed from the uranium atoms that have split. Many of these radioactive elements, as well as the ura-

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Solid-state Physics

An increasingly important aspect of radiation-effects research is concerned with what happens to all sorts of materials when they are exposed to radiation. This research is sometimes chemical in nature because it involves chemical changes caused by radiation, but much of it is in the realm of physics since radiation causes physical properties to change.

When large nuclear reactors were first built, radiation caused noticeable changes in the fuel and in structural materials soon after the reactors were started in operation. Not knowing what the changes were or how serious they might become, scientists started research, during World War II, on radiation's effects on various materials. Plastics, they found, decomposed rapidly under intense radiation. Wood also decomposed quickly. Metals were less seriously affected, but did show changes.

Because of radiation's effects on insulating materials, upon electrical conductivity, and upon the performance of electronic instruments, for example, research in this field is very broad, covering all of the types of materials used in building things that might be exposed to radiation. Naturally, work in this field is carried on with the standard precautions against high radioactivity.

In order to understand how radiation can change physical properties of materials, much fundamental research is necessary. The problems of radiation effects have been

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found to be related to how atoms are "knocked out" of their normal positions. In liquids and gases, atoms move about rather freely and have no normal position, so radiation's effects in these cases are mainly chemical in nature. But in solids, where atoms are fixed in certain positions and where chemical reactions occur less freely, the main effects of radiation are physical. A comparatively new field of science called solid-state physics has developed around the specialized research on how atoms are linked together in solids, on how solids get their physical properties, and on how radiation causes changes.

Metallurgy

The unusual requirements imposed on materials in reactors make many commonly used structural metals unacceptable. In addition, the nuclear energy requirements often make it desirable to use metals about which very little is known. Since the beginning of the power applications of nuclear energy, it has been necessary to devote extensive research to the metallurgy of uranium, plutonium, thorium, and to previously little known metals such as beryllium, which has special properties that make it highly desirable for certain purposes in reactors.

The conditions inside operating power reactors are rather severe for most materials. The temperature is high, corrosive fluids may be present, radiation causès problems, the entire system may be under high pressure. Research to develop new alloys and other materials is very important to the development of more advanced reactors. Also, metallurgical research is very concerned with methods of making things out of metal—with forging, casting, rolling, cutting, welding, and other metal-working opera-

tions. The quality of the material in use is strongly influenced by the way it is made as well as what it is made of.

Much metallurgical research in nuclear energy fields does not involve radiation or radioactive materials at all, nor is it much concerned with the type of radiation-effects research the solid-state physicists pursue, but rather it deals with the fundamental study of metals of all kinds. In addition to metals research, the metallurgists also work on ceramics and "alloys" of ceramics with metals, called "cermets." These materials are especially valuable for high-temperature uses under certain conditions.

The materials problems in nuclear energy applications are such that metallurgical research is certain to be an important field for many years. Career opportunities here will be numerous and attractive.

Biology

The fact that radiation has effects upon living tissue has long been recognized. When people in the wartime Manhattan Project began producing large amounts of radioactive materials with high intensity radiation, it became very important to learn in more detail the effects of radiation and radioactive materials upon people. Since that time, biological research has centered about determining what the effects of radiation are, how they occur, and what can be done to prevent or cure the damaging effects of radiation.

Nuclear energy, which created so many biological research problems, also provided biologists with a powerful new research tool—radioactive tracers. Through their use, as mentioned before, it has been possible to unravel

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many of the mysteries of chemical processes in living tissues. Radiation can also cause mutations to appear in normal reproductive cycles. The study of genetic (hereditary) effects of radiation is a field in itself. It should be noted that not all radiation effects are bad. Using radiation-caused mutations, biologists have developed improved plant varieties. One new kind of wheat, for example, maintains all the good qualities of its parents and in addition is resistant to rust, a wheat disease that destroys crops.

Biological research with living plants and animals does not involve radiation and radioactive materials in the same way as other nuclear energy research does. When tissues are to be exposed to radiation, they are usually taken to a special irradiation facility. After irradiation, they are not radioactive themselves and may be brought back to a standard biological research laboratory for further study. Biological research thus does not usually involve the radiation shielding and remote controls so often required for other types of nuclear energy research.

Biophysics—Health Physics

The particular field of measuring, evaluating, and controlling the potential hazards of radiation and radioactive materials for the people who work with them or may be exposed to them is called health physics. Research in this area has to do with determining what quantities of radioactive materials or of radiation are dangerous to man. The health physicists also are concerned with better methods for measuring quantities of radiation and radioactive materials and with better methods of controlling radioactive materials to minimize potential hazards.

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A part of their research is concerned with determining what would happen if radioactive materials were released by an accident at a nuclear energy plant or by the explosion of a bomb. In addition to following the path of the radioactivity, the scientists seek to determine what effects it causes in plants and in animals that eat contaminated food or drink contaminated water. A similar but more specialized field of study deals with the effects of nuclear weapons. Health physicists play an important role in nuclear weapons tests, both in protecting the test personnel from radiation hazards and in measuring the weapon's direct effects and the delayed effects of radioactive fallout.

Medicine

So valuable are the uses of radiation and radioactive materials in medical research and therapy that hospitals have been established to specialize in these fields of medicine. Most hospitals utilize radioisotope tracers, X-ray treatments, treatments with radiation from radioisotope sources, and other advances in medicine made possible by nuclear energy.

Any medical doctor who wishes to use these techniques may become qualified to do so by taking the special, short training courses that are offered by the Atomic Energy Commission. Of course, in order to be able to use radioisotopes and radiation treatments, the doctor must practice in a hospital that has the special facilities required.

Agriculture

The major application of nuclear energy in agriculture is in the use of tracer techniques. This has permitted rapid

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advances in agricultural research, and is a widely used tool; but here again only a short training course is required to qualify any agricultural researcher to use radioactive tracers. Most agricultural colleges provide this training in their regular course of study.

The use of radiation to create mutations and develop improved varieties is important to agriculture, but so far most of this work has been done by biologists. It is probable that agricultural research centers will do more work in this field as they obtain the special irradiation facilities required.

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CHAPTER VII

Careers in Education

For those who have the ability and interest, teaching is an especially rewarding career. Not only is the work interesting and pleasant, but also the reward of seeing good students learn and develop under your teaching and guidance is especially gratifying. The field of nuclear energy education is one in which the shortage of teachers is especially acute. Thus, opportunities for careers in teaching will be good for years to come.

University Teaching and Research

The demand for trained personnel in all fields of nuclear energy must be met by the universities, where education in scientific fields is traditionally obtained. The requirements for teaching nuclear science involve special laboratory equipment and costly experimental devices, so not all universities and colleges can offer specialized traning in nuclear energy fields. However, the list of institutions possessing research reactors and other facilities for nuclear energy work is growing steadily. These universities offer career opportunities in teaching and research.

The universities have traditionally carried on most fundamental research and have offered the scientist the greatest freedom to pursue his own interests at his own pace. Customarily, university faculty members are assigned teaching loads that allow them time for performing and supervising research. Professors will usually have a number of graduate students working on research projects under their supervision and guidance. Teaching usually occupies morning hours, with laboratory instruction in the afternoons. The professor often does not have the same teaching schedule every day, since most university classes meet only three times a week, and laboratory experiments are scheduled only one or two afternoons a week for each course. The hours between classes and during those afternoons when no student laboratory instruction is scheduled provide the professor with an opportunity to perform research, to read the latest scientific literature, or to follow other professional activities.

Public School Teaching

Since few public schools offer courses as specialized as the nuclear energy fields, teaching opportunities are usually limited to broader areas of science. In high schools, it is usually required that a science teacher have at least a master's degree and that he teach other subjects as well as science. High schools offer little opportunity for research, but they do offer a special challenge to the teacher, for high-school teachers probably have the best opportunity to find scientific talent in their students and to cultivate it into real interest in science. Many scientists have been led into the field by teachers who inspired them.

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Government Educational Programs

The federal government, in its programs of assistance to underdeveloped nations, quite often undertakes educational programs. There are several in nuclear energy fields, with schools located at the National Laboratories of the Atomic Energy Commission. The federal government from time to time sends experts to foreign countries to teach and to train personnel in nuclear energy fields. While these are usually short-term programs, they offer interesting career opportunities that are considerably different from the usual careers in educational fields.

Library and Information Services

While library science is a specialty in itself, much emphasis in the nuclear energy fields is placed on scientific libraries and other information services. Many career opportunities are available at nuclear energy establishments in library and technical information work. The Atomic Energy Commission maintains a large organization within its own staff, called Technical Information Service, which works exclusively with nuclear energy books, scientific journals, and other publications.

Professional and Trade Publications

Professionally trained editors and scientific writers are employed by scientific societies and by publishers to edit and write for technical magazines and other publications concerning nuclear energy work. The major news services —United Press International, for example—have science writers who specialize in articles or reports on nuclear energy.

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The National Laboratories of the Atomic Energy Commission also maintain technical information groups who write, edit, and publish nuclear energy information. This field will grow in importance as it becomes increasingly difficult for scientists to keep up with all that is being done in their fields. There are many career opportunities for those who combine training in scientific fields with training in writing and editing.

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CHAPTER VIII

Selecting a Nuclear Energy Career

Although much has been said about nuclear energy and what it involves and about what the work in these fields is like, you may be wondering, "What do these people in nuclear energy careers actually do?" It would be impossible to describe all of the jobs or even to tell all about any one job, so the following sections will describe what an average worker might be doing on a typical day. Scientific and technical employees are described, because other workers—secretaries and accountants, for example—perform their jobs in nuclear energy fields in much the same manner as they do everywhere else.

A Day's Work in Industry

Industrial careers will center around production operations, such as running a nuclear reactor to produce electric power or a chemical plant to process the fuel from nuclear reactors. Professional personnel who have college training in nuclear science and technology will be supervisors of these operations. Perhaps the most outstanding features of the day's work in nuclear science and technology are the problems and difficulties that will arise

from radiation and the radioactive materials with which personnel must work.

At the nuclear reactor, the reactor engineer may start his day by checking with the supervisor of the shift that is just going off the job to find out how things are going. He may learn that, during the previous shift, radioactive material was spilled on the floor and tracked by employees over an entire section of the building before it was discovered. Cleanup has been started but is not complete. He will assemble a cleanup crew and see that they have protective clothing—overshoes, coveralls, and face masks with air filters, if needed. He will select the proper chemicals to remove the radioactive material and then supervise the task of scrubbing the floor. After the floor has been scrubbed and rinsed—with scrub chemicals and rinse water collected in a special tank connected to the floor drain system—he will have the health physicist check to see if all the radioactive material has been removed. If it has not, more scrubbing will be employed, perhaps using a different method.

When he returns to his office, he may find someone waiting to ask him, "How much shielding will this radioactive material require when we remove it from the reactor?" From prior experience, or perhaps by calculations about the intensity and energy of the radiation, he will provide an answer. He will also tell the questioner to be sure the health physicist is there when the material is removed from the reactor to check for radiation hazards.

Stopping by the control desk from which the reactor is operated, he may learn that the instrument that shows the inlet temperature of the reactor coolant is not functioning properly. He will call the electronic engineer to

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check and repair the instrument and instruct the operator to obtain his temperature data from another instrument that measures the coolant temperature at a different point in the system. Back in his office again, he may attempt to calculate when it will be necessary to add new fuel to the reactor, considering the recent unexpected period of low-power operation during which fuel consumption was low.

Finally, in the log book he will record brief notes of the day's events, together with data on the operation of the reactor. It is interesting to note that except for the special problems of radiation and radioactive materials, his work is not very different from what he might be doing in many industries.

A Day's Work in Development

In a reactor development group, the typical scientific worker would be an engineer. His work very likely would be concerned with testing the performance of some part being developed for use in a reactor system. When he arrives at a little before eight o'clock (his work day is from 8:00 to 4:30), he will at once change clothes, putting on company-furnished clothing. For work involving chemicals, which may splash on clothing, and with radioactive materials and equipment, which may contaminate or soil clothing, companies insist that special clothing be worn. A locker room is provided for changing clothes and for taking a shower at the end of the work day. Company clothing is provided free to the engineer and is laundered and repaired for him by the company.

At eight o'clock, the engineer is out in the test area, where he has a test model of a new pump to be evaluated.

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Because he is concerned with how the pump will perform under the conditions it will meet in the reactor system, he has the pump connected to a piping system that is heated to the reactor's operating temperature and is under the same amount of pressure as the reactor will be. In the reactor, the pump will be used to pump hot, high-pressure water from the reactor to the heat exchanger where steam is generated to produce electric power. The pump test is therefore designed to pump water from a tank through a loop of pipes back into the tank. The pump will run continuously in the reactor, so it runs continuously in the test.

By this particular day, the pump has been running for a month, and it is time to take it apart to observe the condition of its components. After checking the readings of his automatic recording instruments to determine that the pump is performing satisfactorily, he turns it off along with the water heaters and allows the system to start cooling so that it can be disassembled. While it cools, the engineer makes arrangements to have on hand the pipefitters and other craftsmen needed to dismantle the pump by the time it is ready to work on. He then devotes his attention to plotting on a graph the readings obtained from the instruments on the pump system. From these graphs he hopes to be able to predict the rate of wear of the pump parts and to estimate how long it can operate before needing repairs.

When the pump has been taken apart by the craftsmen, the engineer is able to examine the inner parts for evidence of wear, corrosion, or other damage. He may carefully measure the thickness of some parts to determine how much has worn off. Photographs may be taken

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to provide a record of the physical appearance, especially when something unusual is noticed. Some of the parts may be sent to a laboratory for more detailed study of corrosion or for other types of analyses of the condition of the pump after being operated for so many hours.

Having obtained all the data he can from the pump and having sent various parts to the laboratory for further analyses, the engineer may have to wait for completion of the lab tests before he can put the pump back together and resume operation. He may spend an hour or two working on a written report of his pump tests. This report on the progress of the work informs others of the results obtained to date and provides a permanent record so that anyone else wishing to use the pump under similar conditions will not have to repeat the tests.

As he takes a shower and changes back into his own clothing to go home at 4:30, the engineer thinks, "I hope my analyses can be finished in the lab early tomorrow so we can put the pump back together and get it running again before the day is over." He then plans, "If they don't have my lab results, I'll be able to catch up on some of my reading in the engineering journals. Also, I'll have time to talk to other engineers about the tests they are doing on other kinds of pumps. Maybe they'll have some ideas for design changes that will make my pump work better."

A Day's Work in Research

The research scientist, like the industrial engineer, will be concerned with radiation and radioactive materials. His day may begin with a trip to the reactor to attend to some samples that are being irradiated for him. He finds

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that reactor operating personnel have removed the samples from the reactor as scheduled and placed them in a shielded container that, because it is made of lead, is very heavy. A truck will transport the shielded container back to his laboratory, where a crane or hoist will lift the carrier off the truck and place it in the shielded "hot cell," which is designed for remote-control work with highly radioactive materials.

Once the radioactive sample is in the hot cell, the scientist may use mechanical hands in conjunction with remote-control tools to open the sealed container. This can, or "bomb" as it is sometimes called, prevents the radioactive sample from leaking out. After getting his sample out of its container, he may use the mechanical hands to place it in a measuring device, such as a hardness tester for metals, a balance for weighing the sample, or perhaps an instrument for measuring its electrical conductivity. He may dissolve a portion of the sample in acid for chemical study, or if it is already liquid, he may withdraw a portion for chemical analysis. Whatever operations he performs must be done by remote control, and he must never touch the sample directly. Careful scientific work under these conditions requires a well-developed experimental technique that comes from experience plus a certain natural ability.

The data from his measurements will be recorded in a notebook for later analysis and interpretation. After the experiments have been completed and the work has shown a definite conclusion, the data and experimental observations may provide the basis for writing a scientific article for publication in a professional journal.

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scientific seminar, which the scientist will attend to hear of the over-all progress in the research program of which his work is a part. Or perhaps the seminar will be concerned with an entirely different field, and will bring him up-to-date on new developments and broaden his scientific background. In scientific research, keeping abreast of new developments in many fields and cultivating the broadest possible scientific background are important. Scientists attend professional society meetings, read professional journals, and in general participate in all sorts of communications to achieve these desired results.

A Day's Work in a University

When the nuclear physics professor arrives at the physics building in the morning, he may stop by the office to leave for typing some material he has written out by hand at home the previous night. If his first class is early, at 8 o'clock or 8:30, for example, he probably also reviewed his lecture notes the previous night. If his first class is later, he may review his lecture notes before class, always asking himself, "How can I present this material to be most meaningful and understandable to my students?" His first class may be one in introductory physics for first-year students. Afterwards, he will usually have a free hour or two for office work and reviewing the lecture notes for his second class, which, say, is an advanced course in quantum mechanics.

Between morning classes, he is likely to be visited in his office by several students with problems or questions concerning their work under him. After the second class, he may have lunch with students at the cafeteria, with other faculty members at the faculty club, or perhaps with

businessmen downtown for discussion of some community project in which he is involved. Quite often, the professor will walk home for lunch because faculty houses are usually close to the campus and, as he tells his friends, "I need the exercise."

In the afternoon, he will probably devote most of his time to research. He may have several graduate assistants performing experimental work, and it will be necessary to guide them. He will devote considerable attention to seeing that the student assistants understand what they are doing and how to do it properly, because he feels this is important in two ways: It helps the student to learn and to grow as a physicist, and it will also help him do more accurate and reliable work. Afterward, the professor may devote his remaining time to the data already obtained from previous experiments. First, he may find it necessary to make corrections for inherent errors in the data caused by the instruments used in making measurements or by the nature of the experiment itself. Then, the corrected data must be analyzed and interpreted. Finally, because the results of research have greatest value when they are widely known, the professor must prepare a scientific report about the results of his research for publication in one of the journals of physics.

Suddenly, he realizes the afternoon is gone and he has not prepared the questions for a test to be given in class tomorrow. So in the evening he must put aside some time to prepare the questions. In addition, he may plan to do some more writing on his scientific report or to read over and correct the manuscript that was typed for him during the day.

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for him to go shopping or perform some other task, he could have taken the afternoon off. Since he himself chooses his research and sets the pace for working on it, he has freedom to decide that today it can wait while he does something else. Also, the professor usually has the attractive opportunity of taking a rather long vacation during the summer if he so chooses. He may use this "vacation" to work as a visiting scientist in some research laboratory, which is becoming an increasingly common practice.

When Should a Career Choice Be Made?

Students who choose careers in the broad fields of nuclear energy will also have to decide what kind of nuclear energy work interests them most—physics, chemistry, metallurgy, medicine, engineering, or any of a number of other fields important to nuclear science and technology. While it is true that nuclear energy is a scientific field, it offers many nonscientific career opportunities as well. The professional opportunities available in this field are the ones requiring the most specialized training and the most extensive education.

Therefore, the first question to be answered is, "Do I want to be a scientist?" If a student knew he wanted to be a scientist by the time he reached the first or second year of high school, he could begin selecting the elective courses that would help him. For example, he would be helped toward his scientific career if he took all the mathematics courses he could get in high school, because mathematics is important in all branches of science and engineering. The student interested in nonscientific careers in nuclear energy fields should follow the usual

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Those who feel scientific curiosity about what things are, why they are that way, or "what happens when . . ." are showing an interest in science that might lead them to exciting careers in nuclear energy fields. Even for those not interested in science, there is a spirit of adventure, a kind of excitement about working in such a rapidly advancing field. Nuclear energy careers bring those who follow them close to the frontiers of science and technology; and even the nonscientists get a feeling of participating in something new, challenging, and important.

High-school science courses should, of course, be taken by students who are interested in nuclear energy, whether they plan scientific careers or not. Unless he already knows without doubt what field of science he prefers, the student should try to take at least one course in several different fields to help him find out where his major interests lie.

Is it too late for the student who has already completed high school to decide upon a scientific career? Not at all. In college the variety of courses available is much broader than in most high schools. The opportunity to select mathematics, language, and science courses should be taken at the earliest opportunity. However, in most universities and colleges, students pursuing a liberal-arts or scientific education follow the same basic pattern of course work, with the exception of certain electives, for the first two years. Consequently, a firm decision as to what specific educational degree or field of specialization is to be pursued can often be made as late as the third year of college with little loss of time or opportunity.

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to introduce a delay in completing one's college education. At this point, a major change in career plans may make it necessary to go back and pick up courses that were omitted from earlier schedules so that the student could concentrate on others that then seemed more interesting. Yet, how much better it is to make such a change, regardless of whatever delay it may involve, than to continue training for a career in a field that is not the one you like best. Also, a scientist with broad training in two fields may be even better qualified than one who concentrated on a single field all the way through his education.

It is important to recognize that even after graduating from college with a bachelor's degree in a particular field, you can obtain a Ph.D. in a different field without too much loss of time. It is certainly better to spend an extra year or even two at this time in getting training for the field you like best than to spend the rest of your life wishing you had followed a different career.

Finally, it is not impossible for a person trained in one field to follow a career in another field into which his interests or his work have led him. Thus, a chemist may go into a career that is primarily metallurgical or biological in its associations or general kind of work. And he may do so with outstanding success. This is possible because his scientific education continues as he pursues his career. Indeed, the most valuable and useful part of his education may be received after he has embarked on his career. This education comes as a result of association with other scientists, of experience in working in his chosen field, of reading professional journals, books, and

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To summarize, those who decide upon their careers early in life are fortunate in being able to direct their education toward this goal from high-school days. Education is particularly important for a nuclear energy career because of the fact that specialized training is required, especially in the scientific fields. Nuclear energy involves complex technical equipment, and in new fields of science where the phenomena encountered are so different from what we know in our daily lives we must develop a broad scientific background to understand and work with these special problems. Those who do not make up their minds about nuclear energy careers—or who change their minds—until the last years of college have lost little more than the time required to make up the courses they missed earlier. Moreover, even after entering professional life, a scientist may change his career as he follows his interests or the development of his work.

How Do You Make the Choice of a Career?

At some point in his education, the student begins to recognize that he likes certain school work or activities better than others. Usually, some time later, he learns that certain things are important to him. He also finds what his best talents are. These are three good guide posts to use in choosing a career: What kind of activities do you like best? What is important to you? What are your best talents?

By the time he finishes high school, the student ordinarily knows which activities he likes best. At this point,

he may wonder whether his favorite subject or activity could lead to a career for him. The fact is that he can make a career out of almost anything if he is good enough at it. So the student probably should not rule out any of his major interests just because he is not sure how he could make a career for himself. But he should remember that in high school he has not yet had the opportunity to try many of the possible career fields and activities. If the student makes a career choice in high school, he is doing so on the basis of what he likes then. Something may come along later that he likes better, so he should remember that it is possible to change.

What is important to you? This is a vital question in choosing a career; yet, many people fail to consider it until it is too late. Is it important to you that you continue to live in your present home town? If so, you'd better find out whether your career will be useful or even possible there; a student who wants to live in New York City should not plan a career of raising bananas. Is it important to you to be around people most of the time? Do you want to work indoors or out, in a city, a small town, or in the country? If you can make a list of the things that are important to you, it will help you see what kind of a career would be best for you.

What are your main talents? This often will indicate certain types of careers for which you would be well suited. Nuclear energy careers definitely are more rewarding to those who are able to understand and work with things they cannot see directly. If you have a talent for or a particular interest in understanding how a radio works, for example, this same talent would be valuable in a nuclear energy career. But remember that new talents can

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be developed, so don't be too hasty in ruling out a certain career because right now you don't have a talent for it! And also remember that talent is only a general guide post at this early stage in life. If you are best at *doing* things, that suggests one type of career; if you are best at intellectual activities, that suggests other types of careers. Those who choose scientific careers in nuclear energy fields will work with nuclear radiation, which is invisible and can be detected only by special instruments. They must be able to imagine and to think logically about atoms and the nuclei of atoms, which are too small ever to be seen. This suggests that certain talents are especially valuable for careers in the fields of nuclear science and technology. Those who do the best work in nuclear energy careers have or develop the talent of being able to work effectively with radiation and with atoms—with things they cannot see or get their hands on.

Why do these talents make a difference? Why can't a student pick a career, prepare for it, and then go to work? He can! Many people do every year. They go to work without ever having given a thought to choosing a career. And they find jobs, earn a living, and surprisingly often succeed in life very well indeed. Nevertheless, the student who can pick the career that is best for him, who can educate and prepare himself for this career, and then go to work in his chosen field will be happier in his work and have a much better chance of success. The experience of millions of workers shows that when a man has a job suited to his abilities and training—a job he likes—he is a much better worker. And because he is a better, happier worker, he gets ahead faster and further.

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How Important Is the Right Career Choice?

Having read about when and how to choose a career, you may now be asking "What if I make a mistake and somehow choose a career that is not really the best one for me?" Don't worry, all is not lost. The really important thing is that you choose a career in which you are sufficiently interested and talented to enable you to be a good student. After all, that is your career now—being a student—and your first job is to do that well. If you can master the ideas and the information presented in books and in class, you are showing abilities that will be valuable in a nuclear energy career.

It is not usually possible to know beforehand exactly what kind of work will be involved in the job that you take after completing your education. Therefore, it is wise to take advantage of educational opportunities in order to give yourself the broadest possible qualifications in the area of your choice. Nuclear energy fields offer many types of careers in almost every imaginable specialty.

Most companies expect that any new employee, whether he has had previous experience or not, will require a certain amount of training on the job. Consequently, they give training to new employees through company-sponsored training programs and through assigning newcomers to work with experienced men. In this education on the job, the company seeks to make the employee a specialist at the particular job he is to pursue. The student who has developed good learning habits and can master his job training quickly has an advantage at the start. Additionally, young men who

show promise are given opportunities to broaden their experience in the company and thus to prepare themselves for advancement. Often this company training consists mainly of transferring the employee to various departments so that he can learn varied work. Thus, a specialist in a particular field may have opportunities to learn a good deal about other fields and even to change his career completely if he finds a new kind of work in which he can excel.

Finally, education opportunities exist, regardless of location, for those who wish to continue their learning. Most large universities have adult-education programs that include evening classes and correspondence courses. Many companies will help employees attend university classes while they continue to work, because the company benefits when its employees improve their qualifications and knowledge.

In one way or another, you will have many chances to continue learning after starting your career. You will also have opportunities to change the work you are doing. In other words, the choice of a career you make at the very beginning can be changed. The most important thing about making your initial choice is to pick the field in which your talent and interest enable you to do your very best work.

Outside Interests and Talents

To spend all your efforts on educational activities that specifically prepare you for your career would be a mistake. It is easy to become so concerned with the problems of choosing a career and preparing for it that we lose sight of other important things. Look at it this way: In

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this day, most people work on their jobs about 40 hours a week, leaving better than 70 hours (besides those spent sleeping) for other activities. Even those who are so interested or so busy that they work more hours per day and more days per week still do not usually work more than about 60 hours a week.

It is generally agreed that people work most effectively at their jobs when they have outside hobbies or other activities to provide a pleasant change. Nuclear scientists and engineers are among the most enthusiastic hobbyists anywhere. Such pastimes as little theatre, instrumental music, boating, photography, fishing, hi-fi, astronomy, gardening art, and civic affairs interest many scientists so much that they are almost as professional at their hobbies as they are in their careers.

College elective courses provide an excellent opportunity to lay the foundation for an enjoyable and interesting hobby. In addition, our lives apart from our careers place certain demands on us and present us with many opportunities. The most familiar illustration, perhaps, is the home, where appliances must be kept working, the lawn and garden must be tended, and the business affairs of the family must be conducted. A little training along these lines helps a lot in making life more pleasant and enjoyable.

Careers in Nuclear Energy Fields Cover All Phases of Science, Industry and Education

Nuclear energy is a broad field that touches all our lives and offers the widest possible variety of career opportunities. In research, almost all areas of basic and applied science are represented in the effort to learn about

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and use nuclear energy. But scientists don't work alone, despite the references to "scientists in their ivory towers." They have electronics men, welders, lawyers, accountants, glass blowers, industrial-relations experts, secretaries, sheet-metal workers, medical doctors, carpenters, engineers, public-relations men, and others supporting and helping them. These people, in a large research establishment, actually outnumber the scientists more than two to one. Their careers in nuclear energy establishments are not so specialized as those of the scientists, but they usually require some additional training because of the nuclear energy aspects of the work. This additional training is most often received on the job.

In industry, nuclear energy is playing an increasingly important role and providing a growing number of career opportunities. Building and operating nuclear power plants or nuclear-powered submarines are important industrial activities that offer many career opportunities. The use of radioisotopes in industrial processes is increasing, creating a need for more specialists.

Mining uranium and thorium is almost world-wide, and offers careers in foreign countries as well as in the United States. Many foreign countries seeking to exploit nuclear energy are anxious to obtain trained personnel from the United States to help advance their work.

Teaching careers in universities and colleges offering nuclear energy courses are plentiful today and will continue to increase.

The variety of careers in nuclear energy is wide, and the choice is not likely to be limited by lack of opportunity. Instead, the student who is now choosing a future in nuclear energy should be guided mainly by his answers

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CHAPTER IX

Preparing for Your Career

Choosing Your Field—Study Yourself

You should have some ideas by now about what the work is like in various nuclear energy fields. In thinking about preparation for a career, you should first examine your own talents and abilities, your likes and dislikes. It might be helpful to list your talents, interests, and other personal characteristics and to ask others what they can add to the list. It may also help at this point to skim through Chapter VIII again for factors to consider in choosing a career.

After completing your list of abilities, interests, and personal characteristics, you may find it helpful to reorganize the list by putting together the things that seem to indicate one career or another. How many items on your list indicate that mathematics might be a good career for you? How many items point toward engineering? How many items indicate that basic research might be your field? Applied research? Teaching?

If you study yourself thoroughly before picking a field of specialization, you will be much more likely to choose a career for which you are well suited. This, in turn, will

make your college work easier and more interesting. Making the choice of a career in high school or in the first years of college will give you more opportunities to select elective courses that will help in your career. But this is not so important that you should stick with a certain career choice if later you find another one that you like better. Losing time or taking extra courses in order to change to a field you prefer is wise when your future progress and happiness are considered.

Educational Requirements

Nuclear energy fields are scientific and they require the extensive education that is necessary for scientists. If you are thinking of basic research as a career, you should plan to continue your education to obtain a Ph.D. While it is true that jobs can be obtained in research fields by college graduates with bachelor's degrees, the greatest success in this field requires more education. This is true regardless of the field of science chosen. If you want to perform research in any field, you should first complete the educational requirements by obtaining a Ph.D. With the scholarships now available to undergraduates and the fellowships for graduate students, the extra schooling is not too much of a financial burden for the good student. But it should be noted that it is the *good* students who have the best chance to get scholarships and fellowships.

In production work or in applied research and development, the need for education beyond the bachelor's degree is not so important. Most engineers start their careers after receiving no more than a bachelor's. However, it should be noted that continuing your education to a Ph.D. will give you an advantage, especially in the

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applied-research-and-development fields. In production work and in the process or product-development laboratories of industry and of government nuclear energy installations, most technical employees start their careers after receiving a bachelor's degree. There are career opportunities in many fields for the college graduate in industry or in government plants producing nuclear energy materials or products. As nuclear power is used more extensively throughout the world, industrial careers with companies involved in this business will be especially attractive for the college graduate.

Teaching, even in high schools, usually requires an advanced educational degree. Most high-school teachers need at least a master's. Those who consider careers in university teaching must plan on getting a Ph.D. There are only limited opportunities in universities and colleges for instructors who do not have their doctor's degree. Usually, these are temporary positions that are held while the man completes his graduate work for his doctorate. The fact that it is possible to hold an instructor's position while continuing work toward an advanced degree makes it possible to earn a salary while continuing your education. This enables many to continue working toward advanced degrees when they could not afford it otherwise.

How Much Education?

There are jobs in nuclear energy fields for technicians and operators who do skilled work of a technical nature but who need only a high-school diploma to get started. In those jobs the future is limited, but the work may be just as interesting and challenging as the work of college graduates. The best technicians and operators seldom

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earn a top salary as high as the beginning salary of a Ph.D. scientist. This gives an idea of what an education is worth.

The largest number of technical employees in nuclear energy plants and laboratories are college graduates who have only a bachelor's degree. It is possible to rise to the top jobs in industry with this educational background. Unless you wish to pursue a career in research or teaching, a bachelor's degree most often will provide adequate educational qualifications for success. Although it is possible to pursue careers in research with only a bachelor's degree, the best chances for success are obtained by those who have the broader educational background of a Ph.D. The additional time required to obtain a Ph.D. is well spent, as shown by the fact that average starting salaries for Ph.D. men are about 50 per cent higher than those for B.S. graduates.

Ways to Gain Experience

The two basic qualifications all employers examine when interviewing prospective new employees are education and experience. Many students fail to realize the importance of work experience, which they can obtain at the same time that they are pursuing their education. Part-time or summer jobs provide valuable experience, especially when they involve work related to the field of your career. Many industrial and government plants offer summer employment to college students. These jobs often enable the student to see by experience what the work is like in the field he has chosen for his career. The experience and training are valuable. They will help the student see applications of the courses he is studying in

college, and thus he will gain a better appreciation of the value of his education.

In certain fields, especially engineering, some colleges have coöperative programs with industry whereby a participating student goes to school for a period and then works in industry for a period. In addition to providing experience and training on the job, the "Co-op Program" allows students to earn money, which may help pay their college expenses. While the completion of work for the bachelor's degree usually takes about a year longer under this program, the experience and the earnings from working usually make it a very worthwhile venture.

Where to get the money to pay for a college education is an especially serious problem; sometimes students have to work for several years to save enough to go to college. Often it is possible, in cities having a university or college, to take college courses at night while continuing to work at a regular job. By doing this or by working part time while in college, many students can obtain valuable experience and completely pay their own education expenses.

Education on the Job

As referred to earlier, companies hiring new employees from college expect to provide training to teach them the details of the work they are assigned. Beyond this, many companies now have educational assistance plans through which they give financial or other aid to employees who take university courses during their nonworking hours.

Large universities usually have adult-education programs through which university courses that carry credit

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toward a degree are offered during evening hours. Often these university extension courses are offered in other cities as well as at the university. It is possible for employees to obtain advanced degrees in this way while continuing on their full-time jobs. If it should become necessary to spend full time in school for a short period in order to get an advanced degree, companies allow a leave of absence for this purpose. Those who are located in areas where university extension courses are not available will find that large universities offer many courses by correspondence. In this way, a person may take courses from any university, regardless of where he lives.

Opportunities to obtain more education are not hard to find. The person who continues his education after going to work is making himself a more valuable employee to his company. In many cases, the very fact that he is continuing his education is taken by the company to indicate that he is an above-average employee.

Fellowships

Privately endowed foundations, the federal government, and certain other organizations provide fellowships that pay a salary plus certain expenses for scientists to study and do research, or for students to continue their graduate studies. Research scientists may take a leave of absence from their regular jobs to spend a year in further study and research, often abroad at a leading university. Fellowships allow scientists the opportunity to study under the foremost teachers in their fields and to work with them in research.

Fellowships of this type, for established scientists, are obtained by application to the sponsoring organization.

As might be expected, there are more applicants than fellowships, and only those doing outstanding work are given grants.

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CHAPTER X

Seeking Employment

As the time for completing your college education draws close, you will naturally be interested in finding employment. More than that, you would like to know that the job you accept is the best you can get—in terms of salary, your own interest in the work, the opportunities for advancement, and the other factors you consider important. Consequently, you would like to be able to take your choice from several job offers.

How do you get job offers? The most effective way to begin is by sending your résumé to a number of organizations in which you might like to work. The résumé should provide enough information about you to enable the organization to decide whether it would be worthwhile to call you in for an interview about a particular job. Since the résumé will be your first introduction to the organization and since its purpose is to make a favorable enough impression to prompt them to interview you in person, it should be prepared carefully.

The Résumé—an Appraisal of You

A résumé of personal data, experience, and qualifications has no set form. Each person who prepares one may select the type of presentation he thinks will be most effective. In order to decide how your résumé should be organized and presented, it is best, first, to write out all the information that is to be included. Then the information can be consolidated and arranged to emphasize the important things and to "sell" you to the company for the type of job you want.

What information goes into a résumé? Consider what an employer would want to know about you in order to decide whether you are capable of performing the job he has in mind. Remember also that he is trying to hire the best man he can get for the job. The information you give in your résumé must convince employers who do not know you that you would be a good prospective employee. The following information will be needed in the résumé:

Work experience
Education
Talents and interests

The information you should include under these headings is explained in the following paragraphs.

Work Experience

List all the work you have been paid to perform, whether full time, part time, vacation jobs, or occasional work by the day or by the hour. Start with your most recent job and work back. The following questions,

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which an employer might ask, indicate the information that should be included where it is pertinent.

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What company did you work for?

What was your job title?

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What were your duties?

How long did you hold the job?

What experience did you gain that will be useful on another job?

What special skills or talents did you develop on the job?

What interests or personal characteristics made you successful on the job? (initiative, imagination, leadership, ability to work with people, ability to organize, willingness to follow orders, attentiveness to details, etc.)

What did you like best about the work?

What did you like least?

Why did you leave the job?

What person in the company may we ask about your work? (preferably your supervisor)

Not all of these questions need to be answered for each job—just the ones that give important information about you as a prospective employee. Your description of experience on each job should be brief.

Education

Start with the highest education and work back to high school.

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Schools attended, dates.

Degrees obtained, major field, and year.

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College courses; major courses in your field plus other courses that contribute special job qualifications.

Indicate the subjects in which you excelled. List any honors received.

Indicate your ranking in the class—top 10%, top 25%, etc.

High School; if you went to college, list only the name of the school and the year of graduation. Otherwise, give information on courses taken, best subjects, and ranking in class.

Extracurricular activities—club memberships, offices held, athletics, honors received.

Scholarships or fellowships received, portion of school expenses you earned.

Talents and Interests

For many types of jobs in a particular field, the educational requirements may be the same. In these cases, your talents and interests may weigh heavily in determining the job for which you are best suited. The type of information you include here will cover the following topics:

Hobbies—What have you done in your hobby? Have you won any awards? What useful skills have you developed?

Talents—What talents have you developed and how have you used them?

Interests—What general type of work do you like to do? What special interests might help your job?

Personality—Describe yourself honestly.

Study Yourself

After you have prepared the information described above, go back over it as objectively as you can. Put yourself in the employer's place and ask some questions.

1. What type of work is this man best suited for?
2. What training, special ability, or interest does he have that would make him better than average on the job?
3. Would he prefer experimental work or theoretical work?
4. Can he be a salesman? Would he travel?
5. Would desk work suit him?
6. Can he write good reports?
7. Is he ambitious?
8. Could he work in a group, or would he perform his best work alone?
9. Would he prefer basic research or development?
10. Could he become a good supervisor?

As you think about the questions an employer might ask, see if the answers can be found in your résumé. Remember, the only information he will have is what you give him. Be sure your answers are clear, complete, and short. If the questions above cannot be answered from your résumé, you may have omitted some basic information.

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Study the Field

Before you go further with the preparation of your résumé, it would be wise to think about the kind of job you want. College training to the B.S. degree prepares students equally well for a variety of different jobs. If you have a B.S. in chemistry, would you like to work in an analytical chemistry laboratory, a chemical process-development group, a chemical production plant, a sales organization, or perhaps as an information-service technical writer or editor in the chemical field? You should try to determine what type of work you want to be considered for by the employers to whom your résumé is sent. Having in mind the type of job you want will help you to decide what form the résumé should take. There are several forms to choose from.

Developing Your Résumé

The standard résumé usually takes the following form:

Name Address Telephone Number	Field of Specialization or type of work sought

Work Experience—Start with the most recent position and list in reverse order.

Military Service—List top rank achieved and duties.

Education—Start with the most advanced level and list in reverse order to high school. List courses in your field plus others of particular value to the job you seek.

Talents and Interests—List hobbies and skills.

Personal Data—
Date of Birth
Citizenship
Marital Status
Dependents

Another type of résumé can be drawn up to emphasize training, experience, and qualifications for a particular kind of work. In this case, the work experience can initially be listed by company, job title, and dates, with no explanation of duties and responsibilities. Following this list, your experience should be summarized by types of work under appropriate subheadings, such as "Basic Research," "Research Supervision," "Process Development," or others. Under each of these headings write briefly about the work you did and your accomplishments. This sort of résumé will show more clearly what work you are most interested in and what job you are qualified for.

It may be desirable for you to prepare two or three different kinds of résumés slanted toward different types of work. Only one résumé should be sent to any particular employer, but for each prospective employer on your list, you should select the form of résumé that makes the best presentation for the job you want in his organization.

Public libraries and school libraries always have books on how to find a job. From these, more specific information and more ideas on how to prepare a résumé can be obtained. These books will give the advice of experts

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and will pass on to you ideas that have worked for other people. Do not hesitate to use them.

Sending Out Résumés

When your résumé has been prepared and copies have been made for you to send out to prospective employers, you must decide where to send them. Most universities and colleges give extensive help to their students when they are seeking employment. Students should be sure that they take advantage of this assistance, especially in finding out where employment opportunities are available. See your university employment office first to find out what help they can give. They very likely will have available for you lists of prospective employers to whom your résumé can be sent. For additional sources, see the section on "Employment Information" in the Appendix.

Personnel Recruiting

It is the practice of many large companies to send their personnel men to universities and colleges for the purpose of conducting job interviews with students who will soon be completing their education. These interviews offer excellent opportunities for direct contact with companies that are most likely to be interested in you.

Newspaper advertisements are often used to announce when a company representative will be in a particular city to interview job applicants. When these men are available, anyone who is seeking employment should not miss the chance to talk to them. For they, too, are a direct contact with the company.

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Management Consultants

Certain management-consulting firms often undertake the job of finding certain types of employees for companies. Usually, the positions they seek to fill are on the executive level, but sometimes younger men are sought out for special positions.

Employment Agencies

State or municipal employment agencies may offer good opportunities, especially with smaller companies. These agencies make it a point to keep well informed on all job opportunities in their local region. They also can usually provide assistance in making contact with prospective employers, even though the latter may not have reported any current employment openings.

There are also employment agencies that are in the business of finding jobs or finding employees for a fee. Some of these agencies do business all over the country and thus offer a wide range of contacts with industry. These agencies will, as part of their services for which the fee is paid, prepare a résumé for you and actively try to "sell" you as an employee. Since they do not collect their fee until you have accepted a job (the fee often is paid by the employer), these agencies make special efforts to find jobs their clients will accept.

Contacts through Professional Societies

The professional societies, such as the American Chemical Society, the American Physical Society, the American Nuclear Society, and others usually have booths set up during their annual meetings so that com-

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panies can interview prospective employees who attend. The societies also offer, as a rule, some employment or placement services to their members.

Look for What You Want

When you have made contacts with the companies you are interested in and have been interviewed by all that are interested in you, you may have had some job offers made during your interviews. You may also have promises from other companies that they will write or call you later in regard to a specific job offer.

You should not be hasty in accepting a job. If possible, wait until you have had time to consider all offers together. In cases where you must accept a job immediately or lose the opportunity, it may be best not to accept unless you feel confident that it is a job you will really like. If a company fails to offer you the job you want but offers another instead, you may be able to gain further consideration by writing to them or calling on them again.

It is wise to take time and make a careful analysis of the attractive and unattractive features of each job offer in order to choose the best one. It is also wise to keep in mind that after accepting employment, you will probably have opportunities to change jobs within the company if you want to. It may be advantageous to accept a job that is offered in order to be on hand in the company when an opening occurs in a job that interests you more but that you were not offered at the start. The fact that you can change jobs within the same company or even accept a new job with another company means that a wrong decision about which job to accept in the

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Accepting an Offer

When you have considered all factors—type of work, salary, geographic location, etc.—and have decided which job you wish to accept, you are on the threshold of your career in nuclear energy. You will find much to learn by experience, much that could not be covered in college courses and laboratory experiments. This is a part of the challenge of a nuclear energy career—to be able to apply what you have learned in college and to add to your knowledge the newer developments and applications you meet on the job.

It is important that you start your career in nuclear energy expecting to continue learning. Even the scientists who have been specializing in nuclear energy since World War II find it necessary to devote much of their time to learning new developments and research progress in their fields. This, of course, is also one of the advantages of nuclear energy careers—that is, the field is growing and progressing so rapidly that opportunities for growth and advancement in your career are especially challenging.

Therefore, when you notify a company that you will accept their offer of employment, you should be prepared not only to go to work but also to continue to learn. The entire field is concerned with gaining knowledge about nuclear energy and applying this knowledge to benefit mankind.

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CHAPTER XI

On the Job

Just as students get various grades in the courses they take, so the employees of a company are given various ratings for their performance on the job. Employers can recognize their best employees as readily as professors know their best students. On the job, the best education simply prepares you to do the work. The more education you have, the more advanced the work you are prepared to perform.

After your initial employment and your assignment to a particular job, the amount of education you have and the scholastic records you have made suddenly become of secondary importance. Primary emphasis is on how well you do your job. From this point on, your career will be less and less dependent on your educational background and increasingly dependent on your current job performance.

Probably the most important things you can bring with you to your job are the training and education necessary to perform it and the determination to do your best work. So often you will hear that the way to get ahead is to "do a good job." In general—but only in general—this is true. What is wrong with such advice is

that it is too general to mean very much. It is not always possible to answer for yourself the question, "Am I doing a good job?" Sometimes you just cannot tell until you see how things come out.

But if you start with a more specific goal—to do *lots* of good jobs—you can work more effectively and will know where you stand at all times. And this is really the secret of success in your nuclear energy career—to do *every* job as well as you can. The employee who follows this policy and who stays busy at his job will stand out in any organization. He will soon have a record of doing all of his work well and will advance in his career accordingly.

Case Histories

Two actual case histories of men who are still working in the nuclear energy field will show how performance on the job pays off.

The first man had found it necessary, for financial reasons, to drop out of college after two years. Lacking full college training, he was qualified only for the job of technician in a reactor development engineering group. As a technician he assisted the development engineers in performing their tests and experiments. His work was dependable and he did many jobs well. In addition, he took university extension courses in the evenings for college credit to complete his B.S. degree work. It took six years before he was granted a B.S., and during this period, he worked as a technician full time.

When the reactor on which the engineering group was working looked sufficiently promising, an experimental reactor was designed and constructed for actual per-

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formance tests. After construction of the new reactor, he was assigned to the group to test its performance and to put it into operation. He became thoroughly familiar with all parts of the reactor system and was recognized as an expert on how it was constructed and how it operated. His work throughout this period continued to be outstanding.

During test operations of the reactor, his knowledge of all its parts and their functions led to his being given increased responsibility, and finally he was promoted to supervisor of one of the operating crews. While he served as shift supervisor, he completed his course work and received his B.S.

Some time later, he was employed by another company as chief project engineer to oversee the construction and beginning of operation of a reactor the company had contracted to build in a foreign country. Today, he is widely recognized as an expert in reactor construction and test operations. His salary is about $25,000 per year, with certain additional allowances when he is sent overseas for reactor construction jobs. He has been working in nuclear energy for about fifteen years since he had to leave college for lack of money.

In another interesting case, a Ph.D. nuclear physicist began his career with a cyclotron nuclear physics research group. He worked on theoretical aspects of cyclotron design and performance. His theoretical analyses of cyclotron-design problems and his theoretical interpretations of experimental data were very successful. He also became interested in nuclear reactor theory, more or less as a side line. On his own initiative, he read technical books, attended scientific seminars, and dis-

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cussed reactor theory with associates who were expert in this field until he had mastered it. Soon he was requested by the research director to undertake some theoretical analyses of new reactor designs. His work was outstanding, and he rapidly gained recognition as an expert on reactor theory.

One of the new reactors he evaluated on a theoretical basis appeared so attractive that a decision was made to construct an experimental model. He was appointed director of the project to develop, design, and construct the reactor. In this capacity, he was responsible for the research and development activities of about 200 scientists. His salary was roughly $25,000 a year. He had reached this position before his thirtieth birthday, in little more than five years after receiving his Ph.D.

Continue Your Education

From both case histories, the advantages of continued education are apparent. Both formal course work to obtain a degree and study on your own to broaden your scientific background are valuable. It is certainly true that the more you know, the more valuable you are as an employee; and the more you can do, the more opportunities you will have.

Particularly in nuclear energy fields, which are so new that progress is still very rapid, continuing your education is highly advantageous. An important point in this connection is that your employer probably will not specifically suggest that you continue your education in some way. Very likely, the most he will do is give you the opportunity. It is up to you to take the initiative in getting started on educational activities

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CHAPTER XII

Your Career in Nuclear Energy

Nuclear energy fields today are at the frontiers of science and technology, with challenges and opportunities that are unlimited. The long-range growth of nuclear energy research and industrial activities is assured, and young scientists entering the field have the opportunity to grow with the advances in science and technology.

There are several aspects of nuclear energy work in all fields that are important to a successful career. One is the importance of being able to understand the nature of radioactivity and nuclear radiation. Another feature is the importance of mathematics as a tool for research and development. It is no mere coincidence that the world's most advanced electronic computers are located at the National Laboratories under the U. S. Atomic Energy Commission.

Radiation Hazards

Actually, the dangers connected with radioactive materials, while not found in other fields, are not really working looked sufficiently promising, an experimental safety record of nuclear energy installations shows how

well such hazards are kept under control. To some, the danger itself and the need for remote-control operation will be a challenge, to others a disadvantage. Certainly, working under these conditions requires special interests, aptitudes, and personality characteristics. Learning to cope with them may be difficult for one who likes to work with things he can get his hands on. Also, the penalty for sloppy or haphazard work may be severe.

Special rules and procedures are enforced to regulate all work around radiation and radioactive materials. While these rules and procedures are for the protection of employees, they sometimes seem burdensome. An employee who does not understand the nature of radiation and its effects on the human body may not understand why his working time in a strong field of radiation may be limited to three minutes. If the job he is to do takes five minutes, he may be tempted to stay beyond his allowable three minutes to finish. In five minutes, however, he will have received 66 per cent more radiation exposure than he was supposed to.

Another employee working with radioactive materials may be running late when quitting time arrives and may quickly change into his own clothes without taking a shower or checking himself for radioactive contamination. It could be that he will carry to his home some radioactivity, which may contaminate furniture, clothing, or food and thus create hazards for his family. The penalty for failing to obey all rules may be severe.

Mathematics in Nuclear Energy Fields

No matter what type of nuclear energy career you may choose, you will find occasions to calculate radioactive

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decay, radiation intensities, shielding requirements, or similar nuclear energy relationships. The more scientific or technical your work, the more types of computations you will need to understand. Much of the dependence on mathematics results from the fact that radiation, radioactivity, and many other quantities cannot be measured directly but must be computed from some other measured quantity. For both scientific research and engineering, a thorough grasp of mathematics is desirable. The student who has a talent for mathematics will find his nuclear energy work much more understandable and challenging. Very likely he will also be able to advance in his career more rapidly.

Opportunities for Advancement

Rapid growth of nuclear energy applications will provide opportunities for competent nuclear energy specialists to advance more rapidly than is usually possible in most scientific work. Each time a new nuclear power station is built, an organization to operate it must be fully staffed, from the lowest jobs to the highest. Since nuclear energy specialists are still in short supply, those who have the training and ability will be called upon to accept greater responsibility.

The National Laboratories for nuclear energy research under the U. S. Atomic Energy Commission offer research and development careers in all fields of nuclear energy. More rapid growth is taking place in the universities and colleges where research reactors and other facilities for nuclear energy research are being constructed. The universities need people to operate and

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maintain these facilities as well as professors and research scientists to use them.

Industrial employment and advancement opportunities are equally attractive in fields ranging from mining and ore-processing to the manufacture of instruments and equipment for nuclear energy laboratories and plants. Another area of industrial opportunities covers companies that are not directly in nuclear energy operations but that utilize radiation, radioisotopes, or some other application of nuclear energy in their own operations.

On the whole, nuclear energy fields offer opportunities for more rapid advancement than other fields. Also, because of the degree of specialized training and education required and because of the shortage of trained personnel, salaries all along the line are generally higher than average.

Working Conditions

Nuclear energy fields are comparatively new, and so the laboratories, plants, and buildings at nuclear energy centers are new, modern, and specially designed for nuclear energy work. The working conditions are exceptionally good. Health and safety of workers are a primary concern, and extensive safeguards have been established to protect workers. As a consequence, the nuclear energy fields are rated by the National Safety Council as being one of the two safest industries in the country.

Most workers in nuclear energy fields receive two or three weeks' vacation with pay, and they become eligible for longer vacations as their length of service increases. In addition, most organizations provide group health, accident, hospitalization, and life insurance. Retirement

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The fact that nuclear energy research and applications are being pursued in all parts of the United States and many other regions of the world gives a wide range of opportunity in selecting a place to work.

Taking Advantage of the Opportunities

As in any career, those who are most successful in nuclear energy are those who see the challenges in the problems confronting them and have a strong desire to meet these challenges.

Scientific research in particular is a labor of love that can best be performed by the person with an analytical mind who also has a constant urge to tackle new problems. Those who choose scientific careers should have the ability and aptitude to collect data, seek out the facts from the data, and organize and interpret the facts. They must be able to accept failure and have patience to keep trying because scientific research has many unsuccessful experiments and many dead ends. When the research is successful, the study is complete and a new project is started.

But those who are not so inspired or dedicated to research work will find their opportunities and challenges in nuclear energy fields, too. The industrial-production operations in nuclear power plants, radioactive materials processing plants, or other activities will afford many career opportunities for those who like the challenges of production work. All sorts of engineers and specialists will be needed in connection with nuclear energy applications in their fields. These people will find industrial

research or production careers or teaching careers in nuclear science and technology very similar to corresponding careers in long-established fields, except for the special features of radiation and radioactive materials.

Nuclear energy research today is a new frontier of science, with challenges and opportunities that are unlimited. The long-term growth of the science and technology of nuclear energy is assured, and young scientists entering the field have an opportunity to grow with it. In an expanding field, there are many opportunities and the advancement of those who are capable of taking advantage of them is rapid. There are about 33,000 scientific and technical personnel engaged in research on nuclear science and technology under the Atomic Energy Commission, and 50,000 engaged in production activities. Until the past few years, these were the only people working in the field. Today, industrial activities and university teaching and research programs are expanding as rapidly as qualified personnel can be obtained. For many years in the future, there will be more jobs in nuclear science and technology than there are qualified people to fill them. This certainly will mean steady employment and job security plus the unusual opportunities for advancement that come in a rapidly growing field.

Your Own Business

In the short history of nuclear energy research, development, and application, many independent small businesses have been founded. Several of these have grown into large corporations. Enterprising individuals who have a good idea to develop and sell have already demonstrated that opportunities for starting your own business

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in this area are not greatly different from similar opportunities in other fields.

Because the problems and scientific advances of nuclear energy are so new, experts often establish their own businesses to serve as consultants. They undertake nuclear energy work for companies that do not have qualified personnel among their own employees. In a similar way, university professors may be given a contract to perform certain studies or research for a company. There are several fairly large laboratories whose only business is contract research performed for others. Some of these are nonprofit research institutions, others are profitable companies whose business is research and development.

There are nuclear energy information services that have been organized by individuals to collect and publish information on new development in this rapidly advancing field. Their subscribers pay many times the usual magazine subscription rates to obtain weekly or twice-weekly reports on new developments.

Small businesses are being established to offer such specialized information as disposal of radioactive wastes, manufacture of special nuclear energy equipment, inspection of materials by radiographic methods, and preparation of special chemicals containing radioactive tracers.

Your Future in Nuclear Energy

The United States will need a new energy source to supplement or replace coal, gas, and oil at some time during the next century. At that time, our rate of consumption of energy in all its forms will be tremendous. The alternate energy source must be a very large one—

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larger than our reserves of coal, gas, and oil. There is only one likely prospect in view, and that is nuclear energy.

Uranium and thorium can provide fuel for nuclear reactors to produce the world's energy for centuries. Thermonuclear fusion is much more difficult to achieve; but, if successful, it would make nuclear energy fuel out of water and thus would meet mankind's energy needs forever. Thermonuclear fusion research and development is a long-range program of especially challenging interest. The development of thermonuclear reactors is yet in its infancy, and much further research will be needed.

The technology of nuclear power reactors is being advanced rapidly. New reactors are being constructed each year to produce power more cheaply and to incorporate improvements in design and construction. Continued development of nuclear reactors will be necessary to assure that the nation's alternate power source is available when it is really needed. All the problems of handling radioactive materials from power reactors and disposing of radioactive wastes must be solved before large-scale use of nuclear power becomes necessary.

If profitable uses can be found for the fission products in the spent fuel removed from nuclear reactors, benefits will be gained in two ways—use of the fission products will be profitable, and there will be less to store as radioactive wastes. Although much progress has been made in developing new uses for radiation and radioactive materials, the surface has only been scratched. Much more extensive utilization of these valuable nuclear energy by-products is certain to be undertaken as research and development point the way.

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Through nuclear energy research, mankind's most rapid advancement in understanding the basic nature of the world we live in has been made. In all fields of science, nuclear energy is contributing new research tools and information. The challenge of the frontiers of science is clearly heard in the laboratories of nuclear energy research.

The universities that must provide the scientists and engineers to carry forward these nuclear energy programs are hard pressed themselves to obtain faculty members to keep up with gowing enrollments. The need for teachers, instructors, and professors will grow.

The opportunities in all fields of nuclear energy show great promise. Advancement will come rapidly to those who are qualified and who consistently do good work. Your future in nuclear energy is unlimited. It can be whatever you will make it. Your seriousness of purpose in getting an education and your success in applying knowledge and ability to achieve outstanding results will enable you to meet the challenges of the future in nuclear energy and rise to the top of your chosen profession.

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Self-evaluation Test

The following brief test will give you some idea of whether you are suited to work in nuclear energy fields in general. Since the variety of specialties within this area is so extensive, the student who finds himself interested in such a vocation will have to find out by experimentation, study, and other investigation which specialty is best for him.

1. Do you have the kind of mind that works well with abstract concepts? That is, can you visualize and arrange and manipulate symbols that represent something you cannot see or feel?
2. Do you like and are you good at mathematics?
3. Are you interested in science in general?
4. Do you think logically and objectively?
5. Have you a high regard for factual truth? In other words, if you found, after conducting a long and difficult experiment, that the results you hoped for, or even were certain of, proved not to be the case, would you willingly and readily acknowledge this?

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6. Are you deeply curious about the physical "how" of our universe?

7. Are you orderly and thorough and still imaginative?

8. Are you challenged by the unknown, by exploring the infinite mysteries of matter?

9. Would you be good at, or could you at least develop competence in, handling remote-control devices?

10. Would you be willing to abide by necessary safety precautions and not be unnerved by the potential hazards of radiation?

If you have an absolute "No" answer to any of these basic questions, perhaps it would be wise for you to think twice about embarking on a career in nuclear energy. However, if you are merely hesitant to answer "Yes" to one or two of them, it is possible that by devotion and self-discipline you will be able to enter and succeed in this fascinating, expanding, and worthwhile field.

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APPENDIX I

FELLOWSHIPS

The National Science Foundation, 1520 H Street NW, Washington, D. C., was established in 1950 to "promote the progress of science; advance the national health, prosperity, and welfare; and secure the national defense." This agency is responsible for federal fellowship grants in science and engineering, and annually awards hundreds of predoctoral and postdoctoral fellowships in agriculture, anthropology, astronomy, biochemistry, biophysics, botany, chemistry, earth sciences, engineering sciences, genetics, mathematics, medicine, microbiology, physics, psychology, and zoology.

The Atomic Energy Commission has established special fellowships in nuclear science and engineering at first-, intermediate-, and terminal-year graduate levels. These are designed to encourage promising students to undertake graduate studies in nuclear programs leading to master's and doctor's degrees, thus providing a group of highly qualified students each year.

The curricula developed to meet the needs of these students consist of specific courses in nuclear technology as well as courses in which material from this new tech-

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nology has been incorporated. There is ample opportunity for the student to direct his study toward one of the many specialties in the nuclear field, such as reactor materials, shielding and health physics, chemical technology, reactor systems, reactor analysis, or nuclear physics.

Nuclear science and engineering fellowships are available to United States citizens who hold bachelor's degrees in engineering or physical science (chemistry, earth science, mathematics, or physics) and who have completed mathematics through ordinary differential equations. Applicants for first-year fellowships will be required to take the Graduate Record Examinations, which are designed to test aptitude and achievement; these examinations are administered in January at a large number of centers in the United States and overseas. Before a fellowship appointment becomes effective, the fellow must be granted fellowship clearance by the Atomic Energy Commission and must be accepted by a participating university for study leading to an advanced degree.

Qualified graduate students have opportunities for advanced study in virtually every field related to nuclear energy under several special fellowship programs that are administered by the Oak Ridge Institute of Nuclear Studies for the U. S. Atomic Energy Commission and the International Atomic Energy Agency. These programs are concerned with the furtherance and improvement of science education from the precollege through the postdoctoral levels, in the interest of meeting the nation's needs for highly trained specialists in fields that pertain to nuclear energy. Application materials and further infor-

mation concerning any of the following fellowship programs are available from the Fellowship Office, Oak Ridge Institute of Nuclear Studies, Oak Ridge, Tennessee.

Nuclear Science and Engineering Fellowships

Purpose: To encourage promising scientific and engineering students to pursue work in nuclear science and engineering leading to the master's and doctor's degrees. Further, to assist universities in strengthening and expanding academic programs in nuclear fields by providing a core of highly qualified students each year and by stimulating demand for curricula in these areas.

Type: First, intermediate, and terminal years of graduate school, with nonautomatic renewals available for first- and intermediate-year students.

Prerequisites: Bachelor's degree in engineering or a physical science. U. S. citizenship. For first-year students: a scientific aptitude and achievement examination, to be conducted at a large number of centers throughout the country. For second- and terminal-year students: educational background the equivalent of the first-year program.

Duration: Twelve months (two semesters and summer session, or four quarters).

Courses: Full academic schedules, within the scope of the program, to be arranged between university adviser and fellowship appointee.

Stipends: Basic stipend of $1,800 for first year, $2,000 for intermediate year, $2,200 for terminal year. De-

pendency allowance of $500 for spouse and $500 each for a maximum of two dependent children.

Deadline for filing: January 1st.

Health Physics Fellowships

Purpose: To train college graduates for positions in the field of health physics by providing fundamental knowledge in physics, radiation biology and biophysics, interaction of radiation with matter and living systems, dosimetry, electronics and instrumentation, some understanding of principles underlying permissible exposure and prevention of undesirable exposure, and introduction to legal and public-relations aspects of radiation protection.

Type: Graduate study, with a limited number of extensions available to outstanding fellows for additional work to complete the master's degree.

Prerequisites: Bachelor's degree in biology, chemistry, engineering, or physics, with adequate preparation in other related fields and completion of mathematics through calculus. U. S. citizenship. Age, under 35.

Duration: Academic year of formal course work at assigned university, followed by three summer months of practical experience at coöperating Atomic Energy Commission laboratory.

Courses: Full academic schedule within scope of program, to be arranged between university adviser and fellowship appointee.

Stipends: $2,500 for twelve months. Dependency allowance of $350 for spouse and $350 for each minor

child. Payment of normal tuition, required fees, and limited travel allowance.

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Universities:

Harvard University
University of California
University of Kansas
University of Michigan
University of Rôchester
University of Washington
Vanderbilt University

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Coöperating AEC installations:

Argonne National Laboratory
Brookhaven National Laboratory
Hanford Atomic Products Operation
Lawrence Radiation Laboratory
National Reactor Testing Station
Oak Ridge National Laboratory

Deadlines for filing: February 1st.

Fellowships for Advanced Training in Health Physics

Purpose: To train health physicists to the doctoral level to help assure that highly qualified senior scientists in the profession of health physics are available to further the science of health physics and meet the needs of government and industry.

Type: Graduate study leading to the doctor's degree.

Prerequisites: At least two years' experience in health physics, exclusive of training. U. S. citizenship. Age, preferably under 32.

Duration: One calendar year, with opportunity for one-year renewals. Total fellowship period not to exceed three years.

Courses: Full academic schedule within scope of program, to be arranged between university adviser and fellowship appointee.

Stipends: $4,000 annually, with $400 per year for each dependent (normally tax free). Travel allowance from place of residence to university. Tuition and fees.

Institutions: May be chosen by appointee, but must have strong departments in disciplines related to health physics.

Deadline for filing: February 1st.

Additional commitment: Agreement on part of appointee to remain engaged in health-physics work following fellowship completion for period of time equal to period of training received under the fellowship.

Industrial Hygiene Fellowships

Purpose: To train college graduates for positions in the field of industrial hygiene as it expands to include new and complex problems, many related to nuclear industry.

Type: Graduate study leading to the master's degree.

Prerequisites: Bachelor's degree with major in physics, chemistry, or engineering, with additional academic training or industrial experience desirable. U. S. citizenship. Age, under 35.

Duration: Ten months.

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Courses: Full academic schedule within the scope of program, to vary with the university selected and the interests and background of appointee. Public health and biostatistics required in all cases.

Stipends: $2,500 for ten months, with an additional $200 if appointee has had one or more years' graduate work or industrial experience in a related field. Dependency allowance of $350 for spouse and $350 for each minor child. Normal tuition and fees. Limited travel allowance. Financial assistance to attend annual meeting of American Industrial Hygiene Association.

Institutions: University of Pittsburgh, Harvard University, University of Cincinnati.

Deadline for filing: March 1st.

Oak Ridge Graduate Fellowships

Purpose: To provide selected graduate students with the opportunity to utilize the extensive research facilities in Oak Ridge for the conduct of thesis research.

Type: Unclassified research for the doctor's degree or, in a limited number of cases, for the master's degree.

Prerequisites: Completion of all university course work, language examinations, and other requirements for the degree, except the thesis. Application on behalf of student by graduate dean.

Duration: One year, with extensions when necessary.

Selection of thesis problem: To be determined by the interests of the appointee, the interests of the laboratory, and the requirements of the university.

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Graduate committee: To consist of student's faculty adviser, one other faculty member from his university, and two staff members from the laboratory to which he is assigned.

Final examination: To be conducted at the appointee's university, which subsequently awards the degree.

Stipends: Basic stipend of $2,550 for doctoral candidates, $2,150 for master's candidates. Dependency allowance of $500 for spouse and $500 for each minor child. Certain travel allowances, tuition, and fees.

Application: May be filed at any time.

International Atomic Energy Agency Fellowships

Purpose: To provide advanced research training in peaceful uses of atomic energy at universities, technological institutes, special laboratories, and other institutions of higher education in various foreign countries.

Prerequisites: Bachelor's degree in scientific field. U. S. citizenship. In some cases, previous experience in the field of nuclear science.

Duration: Varies from several weeks to five or six years, depending on level of training and requirements of candidate.

Fields: Wide scope within the field of peaceful uses of atomic energy.

Stipends: Range from $100 to $300 monthly, based on cost of living in various countries and subject to revision depending on cost-of-living variations. Addi-

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tional funds for tuition, fees, books, and limited purchase of equipment. Travel expenses.

Institutions: List of countries where institutions for such training are located available on request from the Fellowship Office of the Oak Ridge Institute of Nuclear Studies, P. O. Box 117, Oak Ridge, Tennessee.

Deadline for filing: February 1st.

Selection: To be made by International Atomic Energy Agency from candidates nominated through the Oak Ridge Institute of Nuclear Studies by U. S. Government.

STUDENT JOBS

Summer employment is offered to students by many nuclear energy plants and laboratories. Both government and industrial nuclear energy establishments regularly employ students for summer work that provides valuable training and experience. The Atomic Energy Commission, at its Washington headquarters and at its regional operations offices around the country, also provides summer job opportunities for students. Many private industries afford student employment opportunities, too.

Summer employment is advantageous to the student for the opportunities it gives to see what the work is like in nuclear energy fields. Most students are assigned to assist experienced workers, who will train and guide them in the jobs they are qualified to perform. Students may be assigned as laboratory assistants in research, as temporary workers in production groups, as workers in

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the business or administrative offices, or in other capacities for which they are qualified and for which there is a need. Many organizations consider the employment of temporary summer workers as a part of their employee recruiting program. They hope that students who get to know the work and the company through summer jobs will become full-time employees after completing their education.

Permanent arrangements have been made between some universities and nuclear energy plants or laboratories for students enrolled in a coöperative educational program to work at certain intervals during their schooling. The work periods are established according to the university schedule and are not limited to summer months. Employment opportunities under these educational programs are determined by the university and the organizations with which it has coöperative agreements.

EMPLOYMENT INFORMATION

The annual report of the Atomic Energy Commission gives up-to-date information on government-sponsored work in all nuclear energy fields. It also provides current information on numbers of people employed and salaries paid. In the appendices to the report, major government nuclear energy installations are listed. The annual report may be obtained by writing to the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. The price is usually $1.75.

Industrial nuclear energy activities are the main concern of the Atomic Industrial Forum, Inc. This organiza-

3 East 54th Street,
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tion publishes a list of all companies engaged in nuclear energy work. The list may be obtained by writing to the Atomic Industrial Forum, Inc., 3 East 54th Street, New York 22, New York.

The Atomic Energy Commission regularly prints special reports on employment opportunities in government nuclear energy work. This information may be obtained from the Division of Organization and Personnel, Atomic Energy Commission, 1901 Constitution Avenue NW, Washington 25, D. C.

The Oak Ridge Institute of Nuclear Studies regularly publishes a catalogue of "Educational Programs and Facilities in Nuclear Science and Engineering," which gives useful information on the courses offered and facilities available for teaching and research at a large number of universities. Write to the Oak Ridge Institute of Nuclear Studies, P. O. Box 117, Oak Ridge, Tennessee.

APPENDIX II

Selected Reading List

Darrow, K. K.—"The Renaissance of Physics" The Macmillan Company, New York, 1936.

Darwin, Charles Galton—"The Next Million Years" Doubleday, Garden City, New York, 1953.

Gamow, George—"The Creation of the Universe" The Viking Press, New York, 1952.

"Mr. Tompkins Explores the Atom" University Press, New York, 1952.

"Mr. Tompkins in Wonderland" University Press, New York, 1940.

"Mr. Tompkins Learns the Facts of Life" University Press, New York, 1953.

"One Two Three . . . Infinity" Viking Press, New York, 1947.

Glasstone, Samuel—"Sourcebook on Atomic Energy" Second Edition (revised and updated), D. Van Nostrand Company, New York, 1958.

Hecht, Selig—"Explaining the Atom" Viking Press, New York, Revised Edition, 1954.

Homan, A. Gerlof and Richard R. Tarrice—"Radio-

isotopes at Work for Agriculture" (SRIA-9) U. S. Atomic Energy Commission, 1959.

McMahon, John J.—"Radioisotopes in Industry" (NYO-2977) U. S. Atomic Energy Commission, 1959.

Tarrice, Richard R. and Mark S. Blumberg—"Radioisotopes in Medicine" (SRIA-13) U. S. Atomic Energy Commission, 1959.

U. S. Atomic Energy Commission—"Radioisotopes in Science and Industry" U. S. Government Printing Office, Washington, 1960.

APPENDIX III

Some Professional Societies

The following list shows some of the societies having special nuclear energy sections or dealing exclusively with nuclear energy. Not included are the well-established professional societies that cover nuclear energy aspects in their broad interest in a general professional field.

American Institute of Mining, Metallurgical
and Petroleum Engineers
Institute of Metals Division
Nuclear Metallurgy Committee
29 West 39th Street
New York 18, New York

American Nuclear Society
86 East Randolph Street
Chicago 1, Illinois

American Society for Engineering Education
Committee on Nuclear Engineering Education
University of Illinois
Urbana, Illinois

Health Physics Society
Dr. Russell F. Cowing
194 Pilgrim Road
Boston 15, Massachusetts

Institute of Radio Engineers
Professional Group on Nuclear Science
1 East 79th Street
New York 21, New York

National Academy of Sciences—National Research Council
Committee on Nuclear Science
2101 Constitution Avenue
Washington 25, D. C.

Other Important POPULAR LIBRARY Reference Books

SP15 WEBSTER'S NEW WORLD DICTIONARY OF THE AMERICAN LANGUAGE 50c

The biggest and best pocket-size dictionary available today. Special vinyl laminated cover for greater serviceability.

W1108 HOW TO BE ACCEPTED BY THE COLLEGE OF YOUR CHOICE — Benjamin Fine 75c

Nine out of ten applicants are rejected by the colleges of their first choice. It need not happen to you. That's why experts from leading public educational systems urge you to read this book — *now*. Sound advice and help from a noted educator.

W1107 A DICTIONARY OF SYNONYMS AND ANTONYMS — Joseph Devlin 75c

Your key to writing and speaking clearer, more accurate, richer English. The first low-priced paperback edition of the reference work considered by scholars to be the standard work in its field.

SP114 HOW TO BUILD A BETTER VOCABULARY — Maxwell Nurnberg and Morris Rosenblum 50c

An entertaining guide that will enrich your knowledge of words. "Improving your vocabulary can be fun when you use the easy method set forth in this book."
—Wilson Library Bulletin

All of these important books are available wherever pocket-sized books are sold.

For further information, listings and catalogues, write Vincent Giacco, Director of Educational Sales, Popular Library, Inc., 355 Lexington Avenue, New York 17, New York.

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Avenue , New York 17 ,

To help you choose
the *right* career

Your Future in Nuclear Energy Fields

Reference—D.O.T. 0-35.73
U.S. Bureau of Labor Statistics

Complete information and advice:

What the life of a nuclear scientist or technician is really like
The kind of aptitudes and education you need
Which area to choose: government, industry or teaching?
Where and how to look for the first job
Fellowships, student jobs
List of professional societies that can help you

THE AUTHOR, William E. Thompson, worked on the first historic job of producing uranium-235 on the wartime Manhattan Project. Today, he writes and reports on nuclear science, while serving as Technical Staff Engineer at the Oak Ridge National Laboratory, Oak Ridge, Tenn.

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